Wheeled and Track Vehicle Cost Research Literature Review

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1: EXECUTIVE SUMMARY

Based on Army and Marine Corps Budget Exhibits from 2014, Wheeled and Tracked Vehicles (WTV) programs comprise a major weapon commodity with approximately two billion dollars expended annually in acquisition, and billions more in Operating and Support related costs. These systems are critical to the Army and Marine Corps, and in these budget-constrained times, the cost of WTV programs is a topic of interest. As such, the Services and DoD periodically invest in cost research and cost estimating methodologies for WTV systems and subsystems. This literature review is a survey of published WTV-related cost estimating methodology and database development. The focus was on research and databases developed in the past decade.

With the establishment of the CCDR Project Office in 1997, and the evolution of that office into the Defense Cost and Resource Center 2003, our cost community has benefitted from an influx of Cost and Software Data Reports (CSDRs) over the last decade. WTV databases and associated cost research has been able to leverage CSDR and other cost data, and provide improved tools to the cost analysis community. However, the number of reporting programs is relatively small when considering statistically valid analytical results. While there is a marked improvement in the size of databases and cumulative research, the state of cost estimating for this commodity is somewhat immature, much more data collection and subsequent analysis required.

OSD, Army, Navy, and Marine Corps executives, managers, and senior cost analysts can work together to ensure that major weapon programs develop cost reporting plans for each major contract, and that the level of detail be sufficient to support future cost estimates. Future weapon cost databases updates should include more systematic collection of cost and with greater granularity in WTV subsystem data; this greater detail will support development of WBS Level 3 cost estimating relationships (CERs) at a minimum, and allow analysts to more easily perform design trades. Finally, more attention to WTV operating and maintenance cost, particularly depot costs, needs to be collected and analyzed.

This literature review is a first edition developed by Technomics, Incorporated.

2: HISTORIC COST RESEARCH

The research in Wheeled and Tracked Vehicle cost estimating is marked by balance between Wheeled vs. Tracked systems, and by more concentrated research in recent years. The following studies were reviewed and they generally capsulize the current state of the art in Wheeled and Tracked Vehicle cost research. They are listed in reverse chronological order, and the text in parenthesis following each title is an abbreviation used to reference it throughout the remainder of this document.

1. "Wheeled and Tracked Vehicles Automated Cost Database (WTV ACDB)", prepared by Technomics for ODASA-CE, October 2014 (WTV ACDB 2014)
2. "Below-the-Line Factors for Wheeled and Tracked Vehicles", prepared by Technomics for ODASA-CE, Original March 31, 2014, Revision September 30, 2014 (BTL Factors update 2014)
3. "Bradley Fighting Vehicle Cost per Pound Study", prepared by Technomics for ODASA-CE, Original March 31, 2011, updated in the "Army Ground Vehicle Systems Cost Estimating Bluebook", Appendix B, September, 2014 (BFV Cost per Pound 2014)
4. "Wheeled and Tracked Vehicle Government In-House Cost Database", prepared by Technomics for ODASA-CE, Original January 31, 2012, Revision March 31, 2014 (WTV GIH update 2014)
5. "Vehicle Reference Book (VRB) Series", prepared by Technomics for ODASA-CE, Original October, 2011, Revision March 31, 2014 (VRB update 2014)
6. "Analysis of Technical Data Packages", prepared by Technomics for ODASA-CE, March 31, 2014 (TDP 2014)
7. "Analysis of System Modifications", prepared by Technomics for ODASA-CE, March 31, 2014 (Mods 2014)
8. "Consumables & Reparables Cost Estimating", prepared by Technomics for ODASA-CE, Original 2008, updated March 20, 2012, updated November 20, 2013 (Cons & Reps 2013)
9. "Uncertainty Around Contract Cost Rates", prepared by Technomics for ODASA-CE, Original August 1, 2012, Revision August 27, 2013 (Rates Uncertainty update 2013)
10. "Learning Curve Step-Down Analysis - Abrams Main Battle Tank and Bradley Fighting Vehicle", prepared by Technomics for ODASA-CE, March 30, 2012 (LC Step-Down 2012)
11. "Army Ground Vehicle Systems Bluebook/Sufficiency Book", prepared by Technomics for ODASA-CE, January 2012 (Bluebook update 2012)
12. "Unmanned Ground Vehicles (UGV)", prepared by Technomics for ODASA-CE, March 31, 2011 (UGV 2011)

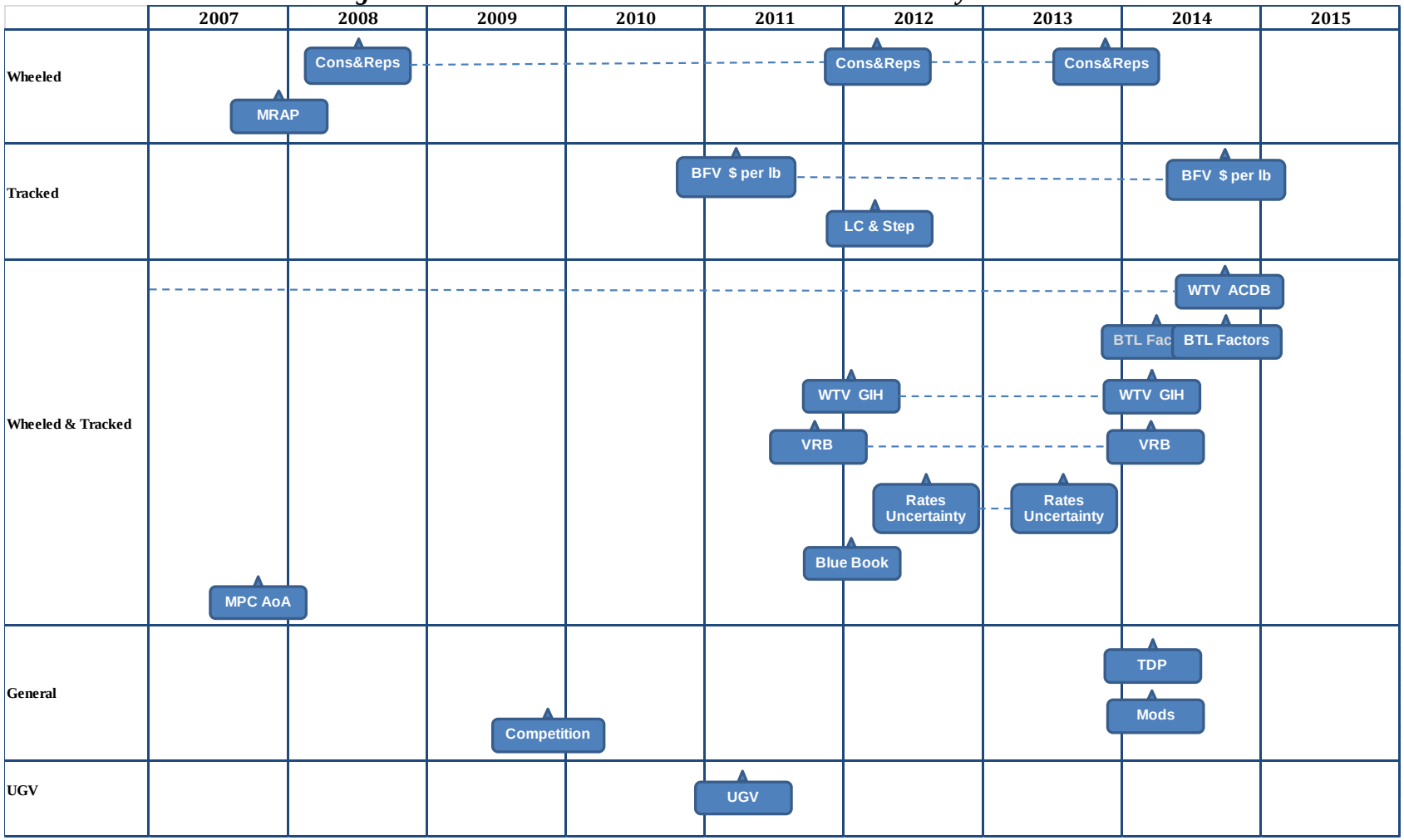
13. “The Effects of Competition on the Acquisition Costs of Ground Vehicle Systems”, prepared by Technomics for ODASA-CE, November 20, 2009 (Competition 2009)
14. “Mine Resistant Ambush Protected (MRAP) Contract Price Analysis”, prepared by Technomics for Tank-Automotive and Armaments Command, December 2007 (MRAP 2007)
15. “Marine Corps Studies Program Support - Marine Personnel Carrier (MPC) Cost and Effectiveness Analysis Support to the MPC Analysis of Alternatives (AoA)”, prepared by Northrop Grumman Mission Systems with support from Technomics for sponsored by Operations Analysis Division, Marine Corps Combat Development Command, October 24, 2007 (MPC AoA 2007)

Figure 2.1 depicts a timeline of the studies examined. Cost research was broken into logical groups based on platform type, including: **Wheeled**, typically tactical or transport trucks; **Tracked**, typically armored combat vehicles; **Wheeled and Tracked**, for studies that address both major platform types; **General**, a category used for non-platform specific analysis; and **Unmanned Ground Vehicles (UGV)** for ground robotic platforms.

Nearly half (7 of 15) of the cost research reports evolve along notable study threads, with several of those (5 of 7) pieces of work updated nearly annually with refreshed, expanded datasets and updated methodology:

- Wheeled
    - Cons & Reps (2008, 2012, and 2013)
- Tracked
    - BFV $ per lb (2011 and 2014)
- Wheeled & Tracked
    - WTV ACDB (2014 and prior, annually)
    - BTL Factors (2014 and 2014 update)
    - WTV (2012 and 2014)
    - VRB (2011 and 2014)
    - Rates & Uncertainty (2102 and 2013)

Figure 2.1 Wheeled and Tracked Vehicle Literature Study Timeline



2.1. "WHEELED AND TRACKED VEHICLES AUTOMATED COST DATABASE (WTV ACDB)", TECHNOMICS, INC., 2014 (AND PRIOR, UPDATED ANNUALLY)

The Automated Cost Database (ACDB) is part of the ACEIT software suite developed by Tecolote Research, Inc. Report Wizard is the ACEIT software tool that allows the user to access information in the ACDB. Specifically, Report Wizard allows a user to create and view reports of database contents; export raw data (cost data in then-year dollars); export mapped and normalized data; perform data queries; view cost, technical, and programmatic specifications for vehicles and their components; and view helpful reference documents that have been attached in their host application[1].

The Wheeled and Tracked Vehicles ACDB is a repository of cost, technical, programmatic, and other information that is utilized when creating new cost estimates for new and improved wheeled or tracked vehicles. The records within the WTV ACDB adhere to the following hierarchical structure: System Type → System → Model → Contract → Task → Source Document. Vehicles are organized by system type, system, and model, while source documents are organized by contract, task name, and source document type. Data are mapped to a work breakdown structure (WBS) derived from the MIL-STD-881B WBS, and MIL-STC-881C WBS where applicable. The cost element structure (CES) to which data are mapped is provided by the Cost Analysis Manual of the Office of the Deputy Assistant Secretary of the Army for Cost and Economics (ODASA-CE)[2].

2.1.1. DESCRIPTION OF DATASET

Cost data is entered into the database as it appears on contractor cost documents. The Contractor WBS is mapped to the WTV WBS (to the lowest appropriate element) and CES structures using mapping rules developed in conjunction with ODASA-CE. The user is able to view raw cost data in the form of cost reports in the form of Cost Data Summary Reports (CDSR, 1921),

[1] Wheeled and Tracked Vehicles Automated Cost Database User's Guide: Examples and Exercises from October 2014 Database. Technomics. October 2014 (pending release)

[2] The Joint Services Wheeled & Tracked Vehicles Automated Cost Database (WTV ACDB) - User's Overview: An Introduction to the WTV ACDB. Technomics. July 29, 2011.

Functional Cost-Hour Reports (FCHR, 1921-1), Cost Performance Reports (CPR, typically Format 1), Cost/Schedule Status Reports (C/SSR) and contracts.

Technical and performance data have been collected from contractor brochures, technical manuals, websites, interviews and meetings. This data consists of hardware information, specifications, and characteristics. As with the cost data, technical and performance data is mapped to the WTV WBS structure (to the lowest appropriate element).

Data in the WTV ACDB is proprietary and may not be shared with your Scientific, Engineering, Technical and Analytical (SETA) contractors unless they have secured all the relevant Non-Disclosure Agreements (NDA) with the hardware makers.

The Table 2.1 displays the content of the WTV ACDB as of October 2014. Descriptions of the content categorizations are also provided below:

Table 2.1: WTV ACDB Content

Wheeled and Track Vehicle ACDB Filter by Characterization	
Number of System Types	45
Number of Systems	201
Number of Models	776

System Type: Attributed to the mission of the vehicle system (i.e. amphibious vehicle, artillery self-propelled, fighting vehicle, main battle tank, personnel carrier, trailer, etc.).

System: Generally tied to a vehicle program (i.e. HMMWV Series 4x4, Joint Light Tactical Vehicle (JLTV) FOV, and Medium Tactical Replacement (MTVR)).

Model: Variant of a vehicle system. Examples of Models in the WTV ACDB are BFVA1, BFVA2, and BFVA3 of the Bradley Fighting Vehicle System.

Tables 2.2 through 2.5 display wheeled and tracked vehicle systems (with unmanned systems denoted with red font), in addition to sub-systems and launcher systems that have data housed within the WTV ACDB as of October 2014.

Table 2.2: WTV ACDB Wheeled Systems

Wheeled Systems	Wheeled Systems
ANDROS	M1070/M1000 HVY EQUIP TRNSPRTR SYS TRAILER 70 TON
ARMORED SECURITY VEHICLE (ASV)	M1070/M1000 HVY EQUIP TRNSPRTR SYS TRUCK 70 TON
CUCV SERIES (CHRYSLER) 1-1/4 TON 4X2	M1073 TRAILER (TRACKED FOR FULL UP PWR PACK - FUPP)
CUCV SERIES (CHRYSLER) 1-1/4 TON 4X2 - AMBULANCE	M1098 SEMI-TRAILER 5,000 GAL (TANKER, WATER)
CUCV SERIES (CHRYSLER) 1-1/4 TON 4X4	M116 TRAILER 3/4 TON/2-WHEEL (CHASSIS)
CUCV SERIES (CHRYSLER) 1-1/4 TON 4X4 - AMBULANCE	M129 SEMI-TRAILER 12-TON/4-WHEEL (VAN, SUPPLY)
CUCV SERIES (GM) 1-1/4 TON 4X4	M149 TRAILER 1-1/2 TON/2-WHEEL 400 GAL (TANKER, WATER)
CUCV SERIES (GM) 1-1/4 TON 4X4 - AMBULANCE	M151 SERIES TRUCK 1/4 TON 4X4
CUCV SERIES (GM) 3/4 TON 4X4	M200 TRAILER 2-1/2 TON/2-WHEEL (CHASSIS, GENERATOR)
FMTV SERIES	M270 SEMI-TRAILER 12 TON LOWBED
FMTV SERIES 10 TON 6X6	M313 SEMI-TRAILER 6-TON/4-WHEEL (VAN, EXPANSIBLE)
FMTV SERIES 2-1/2 TON 4X4	M35 SERIES TRUCK 2-1/2 TON 6X6
FMTV SERIES 5 TON 6X6	M353 TRAILER 3-1/2 TON (CHASSIS)
FMTV SERIES HIGH MOBILITY ARTILLERY (ROCKET) SYSTEM	M373 SEMI-TRAILER 3 TON/2 WHEEL (VAN, ELECTRONIC)
FMTV SERIES LOAD HANDLING SYSTEMS	M416 TRAILER 1/4 TON/2-WHEEL (CARGO)
FMTV SERIES TRAILER	M54 SERIES TRUCK 5-TON 6X6
FUTURE TACTICAL TRUCK SYSTEM (FTTS)	M656 SERIES TRUCK 5-TON 8X8
HEMAT HEAVY EXPANDED MOBILITY AMMO TRAILER 11 TON	M720 DOLLY SET 3 TON (LIFTING, TRANSPORTABLE SHELTER)
HEMTT SERIES	M796 TRAILER 2-1/2 TON/2-WHEEL (UTILITY)
HEMTT SERIES 16 TON	M809 SERIES TRUCK 5-TON 6X6
HEMTT SERIES 19 TON	M822 SEMI-TRAILER (VAN)
HEMTT SERIES 2,500 GAL	M832 DOLLY SET 5-1/4 TON
HEMTT SERIES 30 TON	M860 SEMI-TRAILER (MISSILE, PATRIOT)
HMMWV SERIES 4X4	M870 SEMI-TRAILER 40 TON LOWBED
HMMWV SERIES 4X4 - AMBULANCE	M871 SEMI-TRAILER 22-1/2 TON FLATBED
HMMWV SERIES 4X4 - UTILITY VEH	M872 SEMI-TRAILER 34 TON FLATBED
INTERIM HIGH MOBILITY ENGINEER EXCAVATOR (IHMEE)	M878 YARD TRACTOR
JLTV PRIMARY VEHICLE	M900 SERIES SEMI-TRAILERS 5,000 GAL (REFUELLERS)
JLTV PRIMARY VEHICLE - C2 ON THE MOVE (C2OTM) VEH	M911/M747 HEAVY EQUIP TRNSPRTR SYS TRAILER 60 TON
JLTV PRIMARY VEHICLE - GENERAL PURPOSE (GP) VEH	M911/M747 HEAVY EQUIP TRNSPRTR SYS TRUCK 60 TON
JLTV PRIMARY VEHICLE - INFANTRY CARRIER (IF) INTL VEH	M915 SERIES TRUCK
JLTV PRIMARY VEHICLE - INFANTRY CARRIER (IF) USA VEH	M915 SERIES TRUCK 14 TON 6X4
JLTV PRIMARY VEHICLE - UTILITY (UTL) VEH	M915 SERIES TRUCK 20 TON 6X6
JLTV SECONDARY VEHICLE	M915 SERIES TRUCK 20 TON 8X6
JOINT LIGHT TACTICAL VEHICLE (JLTV) FOV	M915 SERIES TRUCK 8 CUBIC YARDS 8X6
LAV LIGHT ARMORED VEH - AIR DEFENSE VEH	M939 SERIES TRUCK 5 TON 6X6
LAV LIGHT ARMORED VEH - ARMORED ANTITANK VEH	MARCBOT
LAV LIGHT ARMORED VEH - ARMORED MOBILE GUN SYS	MEDIUM TACTICAL TRUCK REMANUFACTURE (MTTR)
LAV LIGHT ARMORED VEH - ARMORED MORTAR CARRIER VEH	MEDIUM TACTICAL VEHICLE REPLACEMENT (MTVR)
LAV LIGHT ARMORED VEH - ARMORED RECOVERY VEH	MEDIUM TACTICAL VEHICLE REPLACEMENT TRAILER (MTVR-T)
LAV LIGHT ARMORED VEH - C2 VEHICLE	MINE RESISTANT AMBUSH PROTECTED (MRAP)
LAV LIGHT ARMORED VEH - COMBAT LOGISTICS VEH	PALLETIZED LOAD SYSTEM (PLS) TRAILER
LAV LIGHT ARMORED VEH - NBC RECON VEH	PALLETIZED LOAD SYSTEM (PLS) TRAILER 16-1/2 TON
LAV LIGHT ARMORED VEHICLE SYSTEM	PALLETIZED LOAD SYSTEM (PLS) TRUCK 16-1/2 TON
LAV SYSTEM (FIGHTING VEH)	RECONNAISSANCE SURVEILLANCE TARGETING VEHICLE
LAV SYSTEM (PERSONNEL VEH)	STRYKER FOV
M101 TRAILER 3/4 TON (CARGO)	STRYKER FOV - ARMORED ANTITANK VEH
M103 TRAILER 1-1/2 TON/2-WHEEL (CHASSIS)	STRYKER FOV - ARMORED MEDICAL VEH
M1048 TRAILER 6 TON/4 WHEEL	STRYKER FOV - ARMORED MOBILE GUN SYS
M105 TRAILER 1-1/2 TON/2-WHEEL (CARGO)	STRYKER FOV - ARMORED MORTAR CARRIER
M1061 TRAILER 5-TON/4-WHEEL (FLATBED, GEN PURPOSE)	STRYKER FOV - ARMORED PERS CARRIER
M1062 SEMI-TRAILER 7,500 GAL (PETROLEUM FUEL)	STRYKER FOV - ARMORED RECONN VEH
	STRYKER FOV - C2 VEHICLE
	STRYKER FOV - COMBAT ENGNR
	STRYKER FOV - NBC RECONN SYSTEM
	XM93E1 FOX NBCRS

Total Wheeled Systems: 160

Table 2.3: WTV ACDB Tracked Systems

Tracked Systems	Tracked Systems
AAAV ADVANCED AMPHIBIOUS ASSAULT VEH	M109 FOV AMMUNITION SUPPORT VEHICLE (FAASV)
AAV AMPHIBIOUS ASSAULT VEHICLE	M109 FOV SELF-PROPELLED HOWITZER
ABRAMS FOV	M113 FOV
ABRAMS FOV GRIZZLY COMBAT MOBILITY VEHICLE	M113 FOV AIR DEFENSE VEHICLE CARRIER
ABRAMS FOV WOLVERINE HEAVY ASSAULT BRIDGE	M113 FOV AMBULANCE
ADVANCED FIELD ARTILLERY SYSTEM (AFAS)	M113 FOV ARMORED COMMAND POST VEHICLE
ARMORED FAMILY OF VEHICLE (AFV) PROGRAM	M113 FOV ARMORED PERSONNEL CARRIER
ARMORED SYSTEMS MODERNIZATION	M113 FOV ARMORED RECOVERY VEHICLE
BRADLEY FVS	M113 FOV CARGO CARRIER VEHICLE
BRADLEY FVS COMMAND & CONTROL VEHICLE	M113 FOV FIRE SUPPORT TEAM VEHICLE
BRADLEY FVS FIRE SUPPORT TEAM VEHICLE	M113 FOV FITTER'S VEHICLE
BRADLEY FVS MULTIPLE LAUNCHED ROCKET SYSTEM	M113 FOV IMPROVED TOW CARRIER
BRADLEY FVS STINGER FIGHTING VEHICLE	M113 FOV MAINTENANCE/RECOVERY VEHICLE
BRIGADE COMBAT TEAM MODERNIZATION (BCTM) UGV - SUGV	M113 FOV MISSILE CARRIER
COMPOSITE ARMORED VEHICLE (CAV)	M113 FOV MISSILE EQUIPMENT CARRIER
CRUSADER	M113 FOV SELF-PROPELLED 107MM MORTAR
CRUSADER ADVANCED FIELD ARTILLERY SYSTEM	M113 FOV SELF-PROPELLED 81MM MORTAR
D7F COMBAT BULLDOZER	M48 FOV AIR DEFENSE GUN
EXPEDITIONARY FIGHTING VEHICLE (EFV)	M48 FOV MAIN BATTLE TANK
FUTURE COMBAT SYSTEM (FCS)	M551 ARMORED RECONNAISSANCE AIRBORNE VEHICLE
FUTURE COMBAT SYSTEM (FCS) MGV FOV	M60 FOV ARMORED VEHICLE LAUNCHED BRIDGE
FUTURE COMBAT SYSTEM (FCS) MGV FOV - C2V	M60 FOV COMBAT ENGINEER VEHICLE
FUTURE COMBAT SYSTEM (FCS) MGV FOV - INDIRECT FIRE VEH	M60 FOV MAIN BATTLE TANK
FUTURE COMBAT SYSTEM (FCS) MGV FOV - MEDICAL VEH	M88 ARMORED RECOVERY VEHICLE
FUTURE COMBAT SYSTEM (FCS) MGV FOV - MOUNTED COMBAT VEH	M9 ARMORED COMBAT EARTHMOVER
FUTURE COMBAT SYSTEM (FCS) MGV FOV - PERSONNEL CARRIER VEH	PACKBOT
FUTURE COMBAT SYSTEM (FCS) MGV FOV - RECONNAISSANCE VEH	PALADIN/FAASV INTEGRATED MGMT (PIM) FOV
FUTURE COMBAT SYSTEM (FCS) MGV FOV - RECOVERY VEH	PIM PRIMARY VEHICLE - SELF PROPELLED HOWITZER (SPH)
FUTURE COMBAT SYSTEM (FCS) UGV - ARV	PIM SECONDARY VEHICLE - CARRIER, AMMUNITION TRACKED
FUTURE COMBAT SYSTEM (FCS) UGV - MULE	SMALL UNIT SUPPORT VEHICLE (SUSV)
FUTURE COMBAT SYSTEM (FCS) UGV - SUGV	SMALL UNIT SUPPORT VEHICLE (SUSV) AMBULANCE
FUTURE SCOUT AND CALVARY SYSTEM (FSCS)	SUGV
GROUND COMBAT VEHICLE (GCV)	TALON
LIGHT FLAIL ROBOTIC SYSTEM	UNMANNED GROUND VEHICLE (UGV)
	XM8 ARMORED GUN SYSTEM

Total Tracked Systems: 103

Table 2.4: WTV ACDB Vehicle Subsystems

Vehicle Subsystems
ACTIVE PROTECTION SYSTEM
AUTOLOADER
AUTOMOTIVE TMDE
BRIGADE COMBAT TEAM MODERNIZATION (BCTM)
CONDUCT OF FIRE TRAINER (COFT)
DRY SUPPORT BRIDGE (DSB)
ENGINE
FCS - DIESEL ENGINE
FCS - MRAAS
FUTURE COMBAT SYSTEM (FCS) ACTIVE PROTECTION SYSTEM
FUTURE COMBAT SYSTEM (FCS) NAVIGATION SYS
HE POWERTRAIN (BATTERY PACK)
HE POWERTRAIN (TRACTION MOTOR)
HEAVY DRY SUPPORT BRIDGE
INVERTERS
TELEOPERATION
TRANSMISSION
ULTRACAPACITOR

Total Vehicle Subsystems: 18

Table 2.5: WTV ACDB Launchers

Launchers
CANNON
FOREIGN HOWITZER
HEAVY MORTAR
INTERNATIONAL HOWITZER
LIGHT MORTAR
XM777 LIGHTWEIGHT 155MM HOWITZER

Total Launchers: 6

Table (sets) 2.6 and 2.7 document the number of cost records in ACDB. To reiterate, records are autoloader entries into the WTV ACDB. For example, it's important to note that there are not 253 contracts in the database for Abrams FOV, but rather 253 contract records. The sums in the following tables may not align with the sums in the WTV ACDB task by system tables on Table (sets) 2.6 and 2.7. This occurrence is sometimes due to instances where a single task may be comprised of more than one record if the task corresponds to a CDSR and FCHR.

Table (set) 2.6: Records for major tracked vehicle programs in the WTV ACDB as of October 2014

Abrams - System Name	# of CDSR	# of Contract	# of CPR	# of FCHR	# of C/SSR	Total
Abrams FOV	11	253	49	12	12	**337**
Abrams FOV Grizzly Combat Mobility Vehicle	0	2	2	0	2	**4**
Abrams FOV Wolverine Heavy Assault Bridge	0	9	1	0	2	**12**
Total	**11**	**264**	**52**	**12**	**14**	**353**

Bradley - System Name	# of CDSR	# of Contract	# of CPR	# of FCHR	# of C/SSR	Total
Bradley FVS	53	140	37	38	25	**293**
Bradley FVS Command & Control Vehicle	0	5	0	0	2	**7**
Bradley FVS Fire Support Team Vehicle	0	9	0	0	1	**10**
Bradley FVS Multiple Launched Rocket System	7	44	10	7	4	**72**
Bradley FVS Stinger Fighting Vehicle	0	2	0	0	0	**2**
Total	**60**	**200**	**47**	**45**	**32**	**384**

Table (set) 2.7: Records for major Wheeled vehicle programs in WTV ACDB as of October 2014

FMTV - System Name	# of CDSR	# of Contract	# of CPR	# of FCHR	# of C/SSR	Total
FMTV SERIES	10	16	2	9	1	**38**
FMTV SERIES 10 TON 6X6	28	0	0	10	0	**38**
FMTV SERIES 2-1/2 TON 4X4	86	36	0	25	0	**147**
FMTV SERIES 5 TON 6X6	228	105	0	63	0	**396**
FMTV SERIES HIGH MOBILITY ARTILLERY (ROCKET) SYSTEM	17	4	0	5	0	**26**
FMTV SERIES LHS	12	0	0	3	0	**15**
FMTV SERIES TRAILER	26	8	0	11	0	**45**
Total	**407**	**169**	**2**	**126**	**1**	**705**

HEMTT - System Name	# of CDSR	# of Contract	# of CPR	# of FCHR	# of C/SSR	Total
HEMTT Series	0	83	0	0	0	**83**
HEMTT Series 16 Ton	0	59	0	0	0	**59**
HEMTT Series 19 Ton	0	75	0	0	0	**75**
HEMTT Series 2,500 Gal	0	52	0	0	0	**52**
HEMTT Series 30 Ton	0	39	0	0	0	**39**
Total	**0**	**308**	**0**	**0**	**0**	**308**

HMMWV - System Name	# of CDSR	# of Contract	# of CPR	# of FCHR	# of C/SSR	Total
HMMWV Series 4x4	0	131	1	0	0	**132**
HMMWV Series 4x4 – Ambulance	0	10	0	0	0	**10**
HMMWV Series 4x4 – Utility Vehicle	0	8	0	0	0	**8**
Total	**0**	**149**	**1**	**0**	**0**	**150**

System Name	# of CDSR	# of Contract	# of CPR	# of FCHR	# of C/SSR	Total
M939 Series Truck 5 Ton 6x6	1	144	0	1	0	**146**

System Name	# of CDSR	# of Contract	# of CPR	# of FCHR	# of C/SSR	Total
MRAP Vehicle	10	2	0	10	0	**22**

Stryker - System Name	# of CDSR	# of Contract	# of CPR	# of FCHR	# of C/SSR	Total
STRYKER FOV	97	24	2	94	0	**217**
STRYKER – ARMORED ANTITANK VEH	6	4	1	6	0	**17**
STRYKER – ARMORED MEDICAL VEH	9	5	1	9	0	**24**
STRYKER – ARMORED MOBILE GUN SYS	8	4	1	8	0	**21**
STRYKER – ARMORED MORTAR CARRIER	9	6	1	9	0	**25**
STRYKER – ARMORED PERS CARRIER	12	7	1	12	0	**32**
STRYKER – ARMORED RECONN VEH	6	4	1	6	0	**17**
STRYKER – C2 VEHICLE	17	10	2	17	0	**46**
STRYKER – COMBAT ENGNR	8	5	1	7	0	**21**
STRYKER– NBC RECONN SYSTEM	5	2	2	5	0	**14**
Total	**177**	**71**	**13**	**173**	**0**	**434**

2.1.2. DESCRIPTION OF CERS

ACDBs are a dataset of cost, technical, and programmatic data; but do not include CERs. Data within the WTV ACDB can be downloaded into a spreadsheet for analysis and CER development.

2.1.3. STRENGTHS AND WEAKNESSES

The primary strength of the WTV ACDB module is the large number of data points. The database spans nearly 40 years, and includes data extracted from every ground vehicle CSDR delivered to the government. In addition, the data base includes data extracted from many other cost resources such as Contracts, C/SSRs, and CPRs. In addition, the database includes technical information on the major ACAT I programs, and many lower ACAT programs.

While seemingly a large number of records for WTV systems, users' expectations should be tempered by highlighting that most records do not provide visibility into WBS Level 3 or lower levels. Depending upon the specific WBS, Level 3 data exists for 20%-30% of the records. This level of detail is most often found where cost reporting had taken the form of CDSR 1921 and FCHR 1921-1 reports.

The data base suffers one primary weakness, and that is the difficulty to search and retrieve data. The backbone architecture is more than 20 years old, and is not efficient by modern standards. Use of the database requires training, and often additional reach-back support.

In addition, the user should be aware that the WTV ACDB module is indeed a database of cost and technical records; there are no CERs or other estimating methodologies housed within ACDB.

2.2. "BELOW THE LINE FACTORS FOR WHEELED AND TRACKED VEHICLES", TECHNOMICS, INC., 2014

The purpose of this study was to develop factors which may be used to estimate the cost of non-manufacturing elements of vehicle development and production. The below-the-line factors

examined correspond directly with the Army's Cost Element Structure (CES). The development phase below-the-line factors for wheeled and tracked vehicles created by this study include Development Engineering, Producibility, Engineering, and Planning (PEP), Development Tooling, and Development Facilities. Production phase below-the-line factors include Nonrecurring Production, Engineering Changes, Operational/Site Activation, Fielding, Training Ammunition/Missiles, War Reserve Ammunition/Missiles, and Modifications. Additionally, factors common to both development and production phases of wheeled and tracked vehicles explored in this study include System Engineering and Program Management, System Test and Evaluation, Training, Data, and Support Equipment. All data for this study was provided by the Wheeled and Tracked Vehicles Automated Cost Database (WTV ACDB). *Jane's Armour and Artillery* was used as a resource in limited cases to verify production quantities.

In addition to determining below-the-line factors, further investigation was conducted regarding the relationship between General & Administrative (G&A) charges and other fees to manufacturing costs. The costs associated with each CES item over the course of a ten year production contract were monitored to outline the spending profile.

The study provides an appendix which presents the "raw" cost data (normalized to base year dollars) for each contract mapped to the Army CES. The data tables are the basis for the factor analysis. The report also includes an appendix for a generalized mapping scheme which help the user understand how the raw data was transformed into a final data set.

2.2.1. DESCRIPTION OF DATASET

Data for this study came entirely from reports collected by the Defense Cost and Resource Center (DCARC), specifically, DD Form 1921 Cost Data Summary Report (CDSR) and DD Form 1921-1 Functional Cost Hour Report (FCHR), both of which are housed in the ODASA-CE WTV ACDB.

The study identified three programs with sufficient data to include in the study for the creation of development factors: Expeditionary Fighting Vehicle (EFV), Joint Light Tactical Vehicle (JLTV), and Stryker. Table 2.8 displays top-level information on the development data.

Table 2.8: Development Data

Program	Contractor	Phase	Contract #	Quantity
EFV	GDAS	SDD-I	M67854-01-C-0001	10
EFV	GDAS	SDD-II	M67854-08-C-0003	7
JLTV	BAE	TD	W56HZV-09-C-0107	8
JLTV	GTV	TD	W56HZV-09-C-0108	8
JLTV	LM	TD	W56HZV-09-C-0109	8
STRYKER	GDLS	EMD	DAAE07-00-D-M051	0

For production factors, six programs were identified with relevant cost data: Mine Resistant Ambush Protected All-Terrain Vehicles (M-ATV), Family of Medium Tactical Vehicles (FMTV), Abrams M1A2 System Enhancement Package (SEP), Stryker, Bradley A3 Modernization, and Bradley M2/M3, M2A1/M3A1, and M2A2/M3A2 variants. Table 2.9 displays top-level information on the production data.

Table 2.9: Production Data

Program	Contractor	Contract #	Quantity
M-ATV	Oshkosh	W56HZV-09-D-0111	3
M-ATV	Oshkosh	W56HZV-09-D-0111	5,219
M-ATV	Oshkosh	W56HZV-09-D-0111	1,400
M-ATV	Oshkosh	W56HZV-09-D-0111	1,460
M-ATV	Oshkosh	W56HZV-09-D-0111	4
M-ATV	Oshkosh	W56HZV-09-D-0111	46
M-ATV	Oshkosh	W56HZV-09-D-0111	177
M-ATV	Oshkosh	W56HZV-09-D-0111	400
M-ATV	Oshkosh	W56HZV-09-D-0111	50
FMTV	BAE	W56HZV-08-C-0460	20,107
FMTV	BAE	DAAE07-03-C-S023	28,814
FMTV	S&S	DAAE07-98-C-M005	9,747
FMTV	Oshkosh	W56HZV-09-D-0159	30,565
Abrams M1A2 SEP	GDLS	DAAE07-01-G-N001	100
STRYKER	GDLS	DAAE07-00-D-M051	2,766
STRYKER	GDLS	W56HZV-07-D-M112	677
Bradley A3 Upgrade	BAE	W56HZV-05-G-0005	450
Bradley A3 Upgrade	BAE	W56HZV-05-G-0005	73
Bradley A3 Upgrade	BAE	W56HZV-05-G-0005	731
Bradley A3 Upgrade	BAE	W56HZV-05-G-0005	578
Bradley A3 Upgrade	BAE	W56HZV-05-G-0005	94
M2/M3	FMC	DAAE07-80-C-9018	100
M2/M3	FMC	DAAE07-81-C-0046	400
M2/M3	FMC	DAAE07-82-C-0001	668
M2/M3	FMC	DAAE07-83-C-A001	678
M2/M3	FMC	DAAE07-84-C-A005	600
M2A1/M3A1	FMC	DAAE07-85-C-A016	655
M2A1/M3A1	FMC	DAAE07-86-C-A047	716
M2A2/M3A2	FMC	DAAE07-87-C-A038	662
M2A2/M3A2	FMC	DAAE07-88-C-A033	554
M2A2/M3A2	FMC	DAAE07-89-C-A026	644

The next step in the process was to map each vehicle's costs from each CDSR to the Army CES. The Army CES is as follows:

1.0 RESEARCH, DEVELOPMENT, TEST, AND EVALUATION (RDT&E)

1.01 DEVELOPMENT ENGINEERING
1.02 PRODUCIBILITY ENGINEERING AND PLANNING (PEP)
1.03 DEVELOPMENT TOOLING
1.04 PROTOTYPE MANUFACTURING
1.05 SYSTEM ENGINEERING/PROGRAM MANAGEMENT
1.051 PROJECT MANAGEMENT ADMINISTRATION (PM CIV/MIL)
1.052 OTHER
1.06 SYSTEM TEST AND EVALUATION
1.07 TRAINING
1.08 DATA
1.09 SUPPORT EQUIPMENT
1.091 PECULIAR
1.092 COMMON
1.10 DEVELOPMENT FACILITIES
1.11 OTHER RDT&E

2.0 PROCUREMENT-FUNDED ELEMENTS

2.01 NONRECURRING PRODUCTION
2.011 INITIAL PRODUCTION FACILITIES (IPFs)
2.012 PRODUCTION BASE SUPPORT (PBS)
2.013 OTHER NONRECURRING PRODUCTION
2.02 RECURRING PRODUCTION
2.021 MANUFACTURING
2.022 RECURRING ENGINEERING
2.023 SUSTAINING TOOLING
2.024 QUALITY CONTROL
2.025 OTHER RECURRING PRODUCTION
2.03 ENGINEERING CHANGES
2.04 SYSTEM ENGINEERING/PROGRAM MANAGEMENT
2.041 PROJECT MANAGEMENT ADMINISTRATION (PM CIV/MIL)
2.042 OTHER
2.05 SYSTEM TEST AND EVALUATION, PRODUCTION
2.06 TRAINING
2.07 DATA
2.08 SUPPORT EQUIPMENT
2.081 PECULIAR
2.082 COMMON
2.09 OPERATIONAL/SITE ACTIVATION
2.10 FIELDING
2.101 INITIAL DEPOT-LEVEL REPARABLES (SPARES)
2.102 INITIAL CONSUMABLES (REPAIR PARTS)
2.103 INITIAL SUPPORT EQUIPMENT
2.104 TRANSPORTATION (EQUIPMENT TO UNIT)
2.105 NEW EQUIPMENT TRAINING (NET)
2.106 CONTRACTOR LOGISTICS SUPPORT
2.11 TRAINING AMMUNITION/MISSILES
2.12 WAR RESERVE AMMUNITION/MISSILES
2.13 MODIFICATIONS
2.14 OTHER PROCUREMENT

For most cost elements, cost data mapped directly, one-for-one, from the DD 1921 CDSR WBS to the Army CES. For Development contracts, this includes applicable WBS elements mapping to CES 1.05 through 1.10. However, for Development Prime Mission Product (PMP) related WBS items, the FCHRs were used to help appropriately map costs into 1.01 Development Engineering, 1.02 Producibility, Engineering, and Planning (PEP), 1.03 Development Tooling, and 1.04 Prototype Manufacturing. The details regarding this mapping can be found in Appendix B of the full study. Table 2.10 depicts available development cost data by CES, by contract.

Table 2.10: Development Cost Data Mapped to Army CES

Program	Contract #	1.01	1.03	1.04	1.05	1.06	1.07	1.08	1.09
EFV	M67854-01-C-0001	X	-	X	X	X	X	-	X
EFV	M67854-08-C-0003	X	X	X	X	X	X	X	X
JLTV	W56HZV-09-C-0107	X	-	X	X	X	-	-	-
JLTV	W56HZV-09-C-0108	X	-	X	X	X	-	-	-
JLTV	W56HZV-09-C-0109	X	X	X	X	X	X	-	-
STRYKER	DAAE07-00-D-M051	X	-	X	X	X	X	X	X

For Production contracts, cost data maps directly, one-for-one, from the DD 1921 CDSR WBS to the Army CES for CES items 2.03-2.13. The PMP WBS elements mapped into either parent CES elements 2.01 Non-Recurring Production or 2.02 Recurring Production based on the categorization within the CDSR. (Costs were not mapped into CES children under 2.01 or 2.02.) Table 2.11 depicts available production cost data by CES, by contract.

Table 2.11: Production Cost Data Mapped to Army CES

Program	Contract #	2.01	2.02	2.04	2.05	2.06	2.07	2.08	2.09	2.10	2.13
M-ATV	W56HZV-09-D-0111	-	X	X	-	-	-	-	-	-	-
M-ATV	W56HZV-09-D-0111	-	X	X	-	X	-	-	-	X	-
M-ATV	W56HZV-09-D-0111	-	X	-	-	X	-	-	-	X	-
M-ATV	W56HZV-09-D-0111	-	X	-	-	X	-	-	-	-	-
M-ATV	W56HZV-09-D-0111	-	X	-	-	-	-	-	-	-	-
M-ATV	W56HZV-09-D-0111	-	X	-	-	-	-	-	-	-	-
M-ATV	W56HZV-09-D-0111	-	X	-	-	-	-	-	-	X	-
M-ATV	W56HZV-09-D-0111	-	X	-	-	-	-	-	-	-	-
M-ATV	W56HZV-09-D-0111	-	X	-	-	X	-	-	-	X	-
FMTV	W56HZV-08-C-0460	X	X	X	-	-	-	-	-	X	-
FMTV	DAAE07-03-C-S023	-	X	X	X	-	-	-	-	-	-
FMTV	DAAE07-98-C-M005	X	X	X	X	X	-	-	-	-	-
FMTV	W56HZV-09-D-0159	-	X	X	X	-	-	X	X	X	-
Abrams M1A2 SEP	DAAE07-01-G-N001	X	X	X	X	-	-	X	X	X	-
STRYKER	DAAE07-00-D-M051	X	X	X	X	X	X	-	-	X	-
STRYKER	W56HZV-07-D-M112	X	X	X	X	X	X	-	-	X	X
Bradley A3 Upgrade	W56HZV-05-G-0005	X	X	-	X	-	-	-	-	-	-
Bradley A3 Upgrade	W56HZV-05-G-0005	X	X	-	X	-	-	-	-	-	-
Bradley A3 Upgrade	W56HZV-05-G-0005	X	X	-	X	-	-	-	-	-	-
Bradley A3 Upgrade	W56HZV-05-G-0005	X	X	-	X	-	-	-	-	-	-
Bradley A3 Upgrade	W56HZV-05-G-0005	X	X	-	X	-	-	-	-	-	-
M2/M3	DAAE07-80-C-9018	X	X	-	X	X	-	-	X	-	-
M2/M3	DAAE07-81-C-0046	X	X	-	X	X	-	-	X	-	-
M2/M3	DAAE07-82-C-0001	X	X	-	X	X	-	-	X	-	-
M2/M3	DAAE07-83-C-A001	X	X	-	X	X	-	-	X	-	-
M2/M3	DAAE07-84-C-A005	X	X	-	X	X	-	-	-	-	-
M2A1/M3A1	DAAE07-85-C-A016	X	X	-	X	X	-	-	X	-	-
M2A1/M3A1	DAAE07-86-C-A047	X	X	-	X	X	-	-	-	-	-
M2A2/M3A2	DAAE07-87-C-A038	X	X	-	X	X	-	-	-	-	-
M2A2/M3A2	DAAE07-88-C-A033	-	X	-	X	X	-	-	-	-	-
M2A2/M3A2	DAAE07-89-C-A026	X	X	-	X	X	-	-	-	-	-

2.2.2. DESCRIPTION OF CERS

Cost factors were developed for Development data at the program level, using CES 1.04 (Prototype Manufacturing) as a base. An excursion is also shown where cost factors were developed using unit cost of CES 1.04 as a base (where unit cost is calculated from CES 1.04/quantity).

DEVELOPMENT:

Development Engineering $ = *f* (Prototype Manufacturing $)
Development Engineering $ = *f* (Prototype Manufacturing $, quantity)

Producibility Engineering and Planning $ = *f* (Prototype Manufacturing $)
Producibility Engineering and Planning $ = *f* (Prototype Manufacturing $, quantity)

Development Tooling $ = *f* (Prototype Manufacturing $)
Development Tooling $ = *f* (Prototype Manufacturing $, quantity)

Systems Engineering/Program Mgt $ = *f* (Prototype Manufacturing $)
Systems Engineering/Program Mgt $ = *f* (Prototype Manufacturing $, quantity)

System Test and Evaluation $ = *f* (Prototype Manufacturing $)
System Test and Evaluation $ = *f* (Prototype Manufacturing $, quantity)

Training $ = *f* (Prototype Manufacturing $)
Training $ = *f* (Prototype Manufacturing $, quantity)

Data $ = *f* (Prototype Manufacturing $)
Data $ = *f* (Prototype Manufacturing $, quantity)

Support Equipment $ = *f* (Prototype Manufacturing $)
Support Equipment $ = *f* (Prototype Manufacturing $, quantity)

Cost factors were developed for Production data at the program level, using CES 2.02 (Recurring Production) as a base.

PRODUCTION:

Nonrecurring Production $ = *f* (Recurring Production$)

System Engineering/Program Management $ = *f* (Recurring Production $)

System Test and Evaluation $ = *f* (Recurring Production $)

Training $ = *f* (Recurring Production $)

Data $ = *f* (Recurring Production $)

Support Equipment $ = *f* (Recurring Production $)

Operational/Site Activation $ = *f* (Recurring Production $)

Fielding $ = *f* (Recurring Production $)

Modifications $ = *f* (Recurring Production $)

In addition to creating below-the-line factors based on the CES, the study provides factors for General and Administrative (G&A), Undistributed Budget (UB), Management Reserve (MR), Facilities Capital Cost of Money (FCCM), and Profit/Loss or Fee (FEE).

General and Administrative (G&A) $ = *f* (Total Contract Cost $)

Undistributed Budget (UB) $ = *f* (Total Contract Cost $)

Management Reserve (MR) $ = *f* (Total Contract Cost $)

Facilities Capital Cost of Money (FCCM) $ = *f* (Total Contract Cost $)

Profit/Loss or Fee (FEE) $ = *f* (Total Contract Cost $)

where, for development efforts:

Total Contract Cost $ = Development Engineering $
+ Producibility Engineering and Planning $
+ Development Tooling $
+ Prototype Manufacturing $
+ Systems Engineering/Program Mgt $
+ System Test and Evaluation $
+ Training $
+ Data $
+ Support Equipment $

where, for production efforts:

Total Contract Cost $ = Nonrecurring Production $
+ System Engineering/Program Mgt $
+ System Test and Evaluation $
+ Training $
+ Data $
+ Support Equipment $
+ Operational/Site Activation $
+ Fielding $
+ Modifications $

One program, the Bradley Fighting Vehicle (BFV) program (spanning M2/M3, M2A1/M3A1, and M2A2/M3A3) reported data across ten consecutive years. This allowed calculation, graphical depiction, and examination of factors over time.

2.2.3. STRENGTHS AND WEAKNESSES

A significant strength of the study is it draws upon all of the available ground vehicle contracts for which there is standardized level-3 cost reporting. In that same vein, a weakness is exposed in the lack of availability of many more data points. This weakness is driven by the fact that most vehicle programs are ACAT II (and lower) and do not require formal cost reporting. The

cost community is left with a handful of development programs and handful of production programs that yield detailed cost data suitable for cost factor analysis.

Each program is different and has unique aspects about its cost data. The study provides summary narrative for many programs describing programmatic or contract issues that inform the data user with cautionary or insightful notes.

The report provides examples with sample calculations intended to help the user in applying the findings to their own work.
Mapping and normalization steps are described and data provided.

2.3. "BRADLEY FIGHTING VEHICLE COST PER POUND STUDY", TECHNOMICS, INC., ORIGINAL 2011, UPDATED IN "ARMY GROUND VEHICLE SYSTEMS COST ESTIMATING BLUEBOOK APPENDIX B", TECHNOMICS, INC., 2014

The purpose of both the original study and the updated study was to facilitate the estimation of combat vehicle procurement costs by using weight-based cost factors. Cost and weight data were collected and mapped in accordance with MIL-STD-881, as possible. Associated cost-per-pound metrics were derived.

2.3.1. DESCRIPTION OF DATASET

The original 2011 study does not provide cost data or weight data; however, the study identifies and describes data sources. All data is from the Bradley M2A2 and M3A2 systems and is categorized below.

- Bill of Material (BOM) – part number, quantity, and cost
- FED LOG – part weight (including packaging)
- Technical Manuals – parts list
- Army OSMIS – part cost
- Weight Tapes – estimated vehicle curb weight and combat weight; detailed parts weight for M2A3 only

The updated 2014 study relied upon the Bradley M2A3 Final Cost Summary Data Report (CSDR) associated with the W56HZV-05-G-0005 contract under Delivery Order (DO) 0002, DO 0009 (FY07) & DO 0011. The production of the Bradley M2A3 vehicles consisted of the electronic digitization of previously fielded vehicles. These (731) vehicles were not built new, but refurbished in cooperation among Red River Army Depot, BAE in Fayette and Aiken, SC, and finally BAE in York, PA. The weight data come from the official weight tape for the BFV M2A3 as provided by the Bradley Program Office. Both the cost and weight data is provided in the study. Tables 2.12 and 2.13 display the work breakdown structure (WBS) and identify the elements with corresponding cost and/or weight data.

Table 2.12: Bradley Cost and Weight by WBS, Level 3 Summary

WBS	RECURRING COST	WEIGHT
1.0 Surface Vehicle System	X	
1.1 Primary Vehicle	X	X
1.1.1 Hull/Frame	X	X
1.1.2 Suspension/Steering	X	X
1.1.3 Power Package/Drive Train	X	X
1.1.4 Auxiliary Automotive	X	X
1.1.5 Turret Assembly	X	X
1.1.6 Fire Control	X	
1.1.7 Armament	X	
1.1.8 Body/Cab	N/A	N/A
1.1.9 Automatic Loading	N/A	N/A
1.1.10 Automatic/Remote Piloting	N/A	N/A
1.1.11 Nuclear, Biological, Chemical	X	X
1.1.12 Special Equipment	N/A	N/A
1.1.13 Navigation	N/A	N/A
1.1.14 Communications	X	
1.1.15 Primary Vehicle Applications Software	N/A	N/A
1.1.16 Primary Vehicle Systems Software	N/A	N/A
1.1.17 Integration, Assembly, Test and Checkout	X	
Cost and weight unaccounted		X

Table 2.13: Bradley Cost and Weight by WBS, Level 4 Detail

WBS	RECURRING COST	WEIGHT
1.0 Surface Vehicle System	X	
1.1 Primary Vehicle	X	X
1.1.1 Hull/Frame	X	X
1.1.1.1 Kit, M3A3 spall liner	X	X
1.1.1.2 Driver's hatch forging	X	X
1.1.1.3 Forging cargo hatch	X	X
1.1.1.4 Bolt on armor kit Bradley A3	X	X
1.1.1.5 Power supply unit	X	X
1.1.1.6 Aluminum extrusion	X	X
1.1.1.7 Armor plate, lower front	X	X
1.1.1.8 Wiring harnesses/cable assemblies	X	X
1.1.1.9 Remaining non-mapped material cost & weight	X	X
1.1.2 Suspension/Steering	X	X
1.1.2.1 Support assembly left kit	X	X
1.1.2.2 Support assembly right kit	X	X
1.1.2.3 Shock absorber, direct	X	X
1.1.2.4 Support assembly left kit	X	X
1.1.2.5 Support assembly right kit	X	X
1.1.2.6 Torsion bar kit left side	X	X
1.1.2.7 Torsion bar kit right side	X	X
1.1.2.8 Bearing, roller	X	X
1.1.2.9 Track (GFE/GFM)		X
1.1.2.10 Road wheels (GFE/GFM)		X
1.1.2.11 Remaining non-mapped material cost & weight	X	X
1.1.3 Power Package/Drive Train	X	X
1.1.3.1 Transmission, Tec,	X	X
1.1.3.2 Engine, 600hp, diesel V8	X	X
1.1.3.3 Generator, 400 amp, d.c.	X	X
1.1.3.4 Final drive	X	X
1.1.3.5 Radiator, engine coolant	X	X
1.1.3.6 Valve, control, fan speed	X	X
1.1.3.7 Wiring harness, branched	X	X
1.1.3.8 Air cleaner assembly (M2A2)	X	X

1.1.3.9 Remaining non-mapped material cost & weight	X	X
1.1.4 Auxiliary Automotive	X	X
1.1.4.1 Color flat panel display	X	?
1.1.4.2 Power control module assembly	X	?
1.1.4.3 Assembly, power control module	X	?
1.1.4.4 Position interface box (PIB)	X	?
1.1.4.5 Assembly, system control box	X	?
1.1.4.6 Fuel system	X	X
1.1.4.7 CMED	X	?
1.1.4.8 Sensor, fire detection	X	?
1.1.4.9 Commander's data entry	X	?
1.1.4.10 Blower	X	?
1.1.4.11 Signal distribution box	X	?
1.1.4.12 Hull power box	X	?
1.1.4.13 Vehicle motion sensor II	X	?
1.1.4.14 Heater, air, elect, filter, M3	X	X
1.1.4.15 Wiring harnesses	X	?
1.1.4.16 Remaining non-mapped material cost & weight	X	X
1.1.4.17 Bradley urban survivability kit II	X	?
1.1.5 Turret Assembly	X	X
1.1.5.1 Turret power box (TPB)	X	?
1.1.5.2 Forging, hatch, commander's	X	X
1.1.5.3 Traverse bearing assembly,	X	X
1.1.5.4 Slip ring assembly	X	X
1.1.5.5 Assembly, external training	X	?
1.1.5.6 Resolver, traverse position	X	X
1.1.5.7 Fan, cooling	X	X
1.1.5.8 Turret armor	X	X
1.1.5.9 Fan, ventilating	X	?
1.1.5.10 Wiring harnesses/cable assemblies	X	?
1.1.5.11 Turret drive system (L-3 COM)	X	X
1.1.5.12 CFM for TDS (L-3 COM)		?
1.1.5.13 Remaining non-mapped material cost & weight	X	X
1.1.6 Fire Control	X	
1.1.6.1 Assembly, gun control unit	X	X
1.1.6.2 Resolver, gun position	X	X
1.1.6.3 Assembly, gunners/comm sight	X	X

1.1.6.4 Resolver, TOW position	X	?
1.1.6.5 Cable assembly, IBAS-HTI (2W112)	X	?
1.1.6.6 IBAS shield assembly	X	X
1.1.6.7 IBAS (DRS)	X	X
1.1.6.8 Mono Block (DRS)	X	?
1.1.6.9 CIV (Raytheon)	X	X
1.1.6.10 TPU/GHS/CHS (EFW)	X	X
1.1.6.11 Remaining non-mapped material cost & weight	X	?
1.1.7 Armament	X	
1.1.7.1 TOW missile launcher	X	X
1.1.7.2 25mm gun system (ATK)	X	X
1.1.7.3 RRAD Services (Gun System)	X	?
1.1.7.4 Remaining non-mapped material cost & weight	X	?
1.1.8 Body/Cab	N/A	N/A
1.1.9 Automatic Loading	N/A	N/A
1.1.10 Automatic/Remote Piloting	N/A	N/A
1.1.11 Nuclear, Biological, Chemical	X	X
1.1.11.1 Filter, gas-particulate	X	X
1.1.11.2 Remaining non-mapped material cost & weight	X	?
1.1.12 Special Equipment	N/A	N/A
1.1.13 Navigation	N/A	N/A
1.1.14 Communications	X	
1.1.14.1 Assembly, ethernet switch	X	?
1.1.14.2 M2A3 CPU mounting assembly	X	?
1.1.14.3 Remaining non-mapped material cost & weight	X	?
1.1.15 Primary Vehicle Applications Software	N/A	N/A
1.1.16 Primary Vehicle Systems Software	N/A	N/A
1.1.17 Integration, Assembly, Test and Checkout	X	
1.1.17.1 Teardown & Veh Inspection-RRAD (Phase 1)	X	N/A
1.1.17.2 Disassembly/Refurbishment (Fayette)	X	?
1.1.17.3 Small Component Manufacturing (Aiken)	X	?
1.1.17.4 Final Assembly (York)	X	N/A
Cost and weight unaccounted		X

2.3.2. DESCRIPTION OF CERS

The original study resulted in no cost factors or CERs.

The follow-on study yielded cost per pound metrics for level 3 and level 4 WBS elements as detailed above. General commodities, mechanical, armament, electrical and electronic components, the cost-per-pound factors show ROM trends.

2.3.3. STRENGTHS AND WEAKNESSES

The original study revealed inconsistency in parts identification and numbering among data sources cited, resulting in difficulty in aligning datasets. When the alignment was achieved, data anomalies were evident. Discrepancies in the data led to reduced confidence in the data from each source. A couple years later, a second attempt was made to study and derive cost per pound metrics.

The updated study demonstrates more consistency in pairing cost and weight than the original study, although the user must be cautious in application. The cost and weight data reflects refurbished vehicles. The data and resulting metrics would differ from all-new production. The cost analyst using this data should consider whether or not these costs are relevant to other situations. In this regard, the data and analysis has limited application. As a further word of caution, do not use factors appearing on the level three element rows. Notice for example, that element 1.1.4 included many level-four costs without corresponding weights.

2.4. "WHEELED AND TRACKED VEHICLE GOVERNMENT IN-HOUSE COST DATABASE", TECHNOMICS, INC., ORIGINAL 2012, UPDATED 2014

Estimating ground vehicle government in-house (GIH) costs has traditionally been a difficult task. These costs are not documented in contractor cost reports, and visibility below top level documents is not available outside the program offices. The purpose of this study is to characterize these costs for application in future estimation of GIH costs.

The study of GIH costs of program offices for Army ground vehicles was initiated in 2011. Every year since the study's initiation, data has been collected, analyzed, verified, and mapped to specific cost elements. This 2014 edition compiles previous and most recent data collection efforts. The aim is to amass a database sufficient to support the estimation of the costs to manage ground vehicle program offices in a variety of acquisition and sustainment situations.

2.4.1. DESCRIPTION OF DATASET

The study team worked directly with major ground vehicle program offices to obtain GIH cost data from such documents as staffing plans and records, Military Interdepartmental Purchase Requests (MIPRs), and contracts. This data varies from being highly detailed to relatively sparse. The approach includes developing the data formats and forms of communications with the program offices, making sure that data is understood, and correctly mapped to the correct cost element structure areas.

Originally, the intent was to collect GIH cost data and map it to each of the "support elements" consistent with MIL-STD-881, to include: SE/PM, System Test & Evaluation, Training, Data, Peculiar Support Equipment, Common Support Equipment, Operational Site Activation, Industrial Facilities, and Initial Spares. Based on a meeting with the Stryker Program Office, the group concurred that the vast majority of GIH cost could be mapped to Systems Engineering/Program Management (SE/PM) and Testing. Data collection and mapping to other elements would have been too onerous for program offices to parse the data accordingly. This realization resulted in the development of SE/PM and Testing templates for future GIH cost data collection.

The detail varied from program office to program office. The study team attempted to collect more detailed data and the next lower level of indenture, Level 2. Level 2 SE/PM includes: Core Support, Matrix Support, Other Government Agencies, and Contractor Support. Level 2 Testing includes: Analysis and Evaluation, Developmental Testing, Live Fire Testing, "blank", Test Support, and Test Site Cost. ("Blank" was used to map Testing costs in instances where no other "Level 2" element had been identified. Consider "blank" to be "unspecified.") Table 2.14 shows the SE/PM and Testing GIH cost data collection templates.

Table 2.14: GIH Cost Data Collection Template

"Level 1" Mapping	"Level 2" Mapping
SE/PM	Core Support
	Matrix Support
	Other Government Agencies
	Contractor Support
Testing	Analysis & Evaluation
	Developmental Testing
	Live Fire Testing
	"blank"
	Test Support
	Test Site Cost

Table 2.15 displays the programs included in the GIH database, segregating programs by Tracked vs. Wheeled systems. Columns indicate the Level 1 cost element and the associated years of cost data. An initial set of nine programs include several years of data; those programs have been participating in this recurring data collection effort. In this latest installment, the study team was able to expand their portfolio to a total of 13 programs.

Table 2.15: WTV Programs GIH Cost Data Collection by Element by Year

	SEPM	Testing
TRACKED VEHICLES		
Abrams Tank	2009-2011, 2013	2013
Bradley Fighting Vehicle (BFV)	2009-2011, 2013	2013
Self-Propelled Howitzer System (SPHS)	2013	2013
WHEELED VEHICLES		
Stryker	2000-2012	2001-2012
Mounted Maneuver	2013	n/a
Armored Multi-Purpose Vehicle (AMPV)	2013	n/a
Joint Light Tactical Vehicle (JLTV)	2008-2010	2008-2010
Mine-Resistant Ambush Protected (MRAP)	2009-2013	2009-2013
High Mobility Multi-purpose Wheeled Vehicle (HMMWV)	2010-2013	n/a
HMMWV RECAP	2010-2013	n/a
Light Tactical Trailer (LTT)	2010-2012	n/a
HMMWV Modernized Expanded Capacity Vehicle (MECV)	2012	n/a
Medium Tactical Vehicle (MTV)	2011-2013	2011-2013

2.4.2. DESCRIPTION OF CERS

While no formal CERs were developed, the database includes an accompanying Data Visualization Tool (VAT). The tool allows the analyst to identify trends among the GIH data collected from WTV program offices over the last four years. The tool arranges the data into four categories: Programs, Appropriations, Level 2 GIH Cost Elements and Services. By selecting/deselecting various data sets under each category, it is possible to observe interesting trends among these data sets. An example display is provided in Figure 2. (The colors have been turned off to all black to mask the cost of programs.)

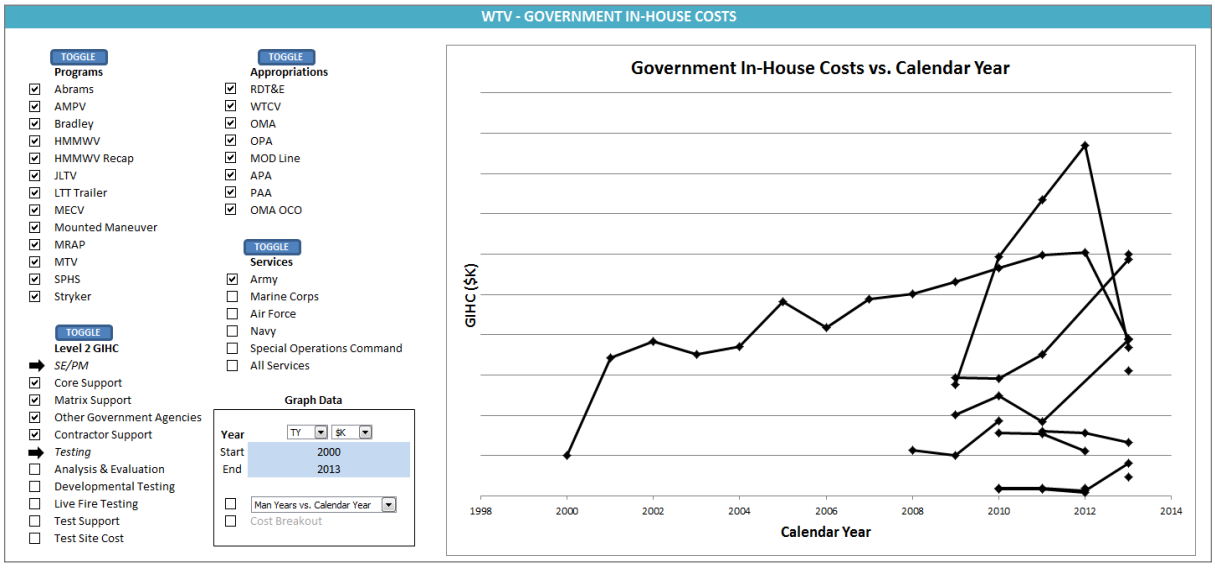


Figure 2 – GIH Cost Data Visualization Tool

With supplemental programmatic, schedule, and contractor costs, it may be possible for the analyst to use the data to prepare influence diagrams, cost factors, and perhaps CERs.

2.4.3. STRENGTHS AND WEAKNESSES

A key strength is that this is the first such study that the Army is aware of that is systematically collecting and organizing WTV GIH cost data. Since this is relatively new, there is only a single year or few years of data per program, with the exception of the Stryker program's 13 years of data.

A key weakness in this study is the lack of contextual information surrounding all of the programs. Without context, the reader needs to collect additional information from outside sources to understand the work scope and causes of increasing trends or decreasing trends.

Finally, the study states, that in working directly with program offices, "…there is a clear understanding that the cost data is to remain confidential and not to be shared with other program offices or parties. In other words, it is the expectation of the program offices that the raw data is to remain within ODASA-CE and not to be shared with other organizations. However, the program offices agreed to share any analyses, conclusions, and/or methodologies derived from the raw data set. To respect the decisions of the program offices, all axes pertaining to cost have been removed from figures…"

2.5. VEHICLE REFERENCE BOOK (VRB) SERIES", TECHNOMICS, INC., ORIGINAL 2011, UPDATED 2014

The objective of the Vehicle Reference Book (VRB) is to serve as reference manuals for selected wheeled and tracked vehicles, providing program history, current status, and planned activities of the fleet. These references are specifically created to assist cost analysts by providing contextual material necessary to understand vehicle configurations, contracts, and life cycle events occurring within the fleets.

2.5.1. DESCRIPTION OF DATASET

The VRB are a series of volumes containing reference material summarizing the ACAT I Army wheeled and tracked vehicle programs, including:

- Tracked:
  - Abrams Tank (91 pages)
  - Bradley Fighting Vehicle (87 pages)
- Wheeled:
  - Family of Medium Tactical Vehicles (FMTV) (63 pages)
  - Mine Resistant Ambush Protected (MRAP) vehicle (102 pages)
  - Stryker (101 pages)

In addition, a sixth volume is in the works. A draft VRB for the (wheeled) Joint Light Tactical Vehicle (JLTV) program is in process.

Each VRB follows a prescribed template and order, to include:

1. System Description
2. Program Organization and Points of Contact
3. System History (including configurations, capabilities, and quantities)
4. System Status (including current issues and plans)
5. Acquisition History (including APB and SARs)
6. Acquisition Status (including funding by life cycle phase, and contracts)
7. Operation & Sustainment History
8. Operation & Sustainment Status
9. Schedule Milestones
10. Cost Data Status (including DCARC CSDR reports & dates, and WTV ACDB holdings)
11. Cost Estimating Status

- References

The following paragraphs summarize the typical contents in each VRB chapter.

1. **System Description**
   The first chapter provides a succinct statement of a system's mission, its purpose, and the system's targets and threats. The chapter continues with a short system description, highlighting notable features and major subsystems. Tables are included which display major physical and performance specifications. In addition, graphics are included showing the systems' general configuration. Finally, notes on Foreign Military Sales (FMS) document the countries buying the systems, accompanied by quantity information when available.

2. **Program Organization and Points of Contact**
   The chapter includes an organizational chart showing how the program fits within the larger context of the PEO, and a second organizational chart displaying the branches or Integrated Product Teams (IPTs) within the system's program office.

3. **System History**
   The third chapter provides a narrative on the origins of the program, and continues with a description of the system's evolution to current day configuration. The narrative describes major hardware changes accompanying the major configuration updates, as well as graphics packed with information to help the reader understand and follow the progression. Additional tables and images present timelines, technical, physical, and performance metrics, and pictures of each variant. The narratives describe the interrelationships among configurations and family of vehicles, as applicable. Summary, historic quantity information is documented, identifying numbers of units by configuration produced to date.

4. **System Status**

   Chapter four reviews where the program is along the life cycle timeline of phases, with some programs straddling across several phases simultaneously, having multiple sub-programs. Dispensation of assets is described, including fielding, upgrade programs, or retirement activities, as applicable. Key issues, as reported in the annual Selected Acquisition Report (SAR), are highlighted and summarized. The section also documents program plans going forward, such as modernization, major Engineering Change Proposals (ECPs), upgrades, and other. The narrative is accompanied by graphics depicting system and subsystem updates and timelines of changes. In addition, the VRB reports on the status of on-going contract execution and development/procurement efforts.

5. **Acquisition History**

   This chapter provides a narrative of genesis of program with history and dates of major milestones. In addition, tables from the latest SAR are reproduced showing Total Acquisition Cost and Unit Cost.

6. **Acquisition Status**

   Chapter six typically starts with an introductory description of current work and current program status. The chapter provides a summary of total program costs to date, including a table showing annual program cost in then-year dollars and the quantity by appropriation as pulled from the SAR. A second table is provided to help the analyst trace back to budget documents and costs, in which data fields include Appropriation, Service (when multi-Services are involved), Program Element (PE) Number, Budget Activity number, and Program element titles associated with the program.

   Significant documentation and tables are provided for major (historic) contracts and on-going contracts. One table lists significant production contracts that exist in the Wheeled Tracked Vehicle (WTV) Automated Cost Database (ACDB), including the contract number, contractor name, and task name. Another table lists the most recent major contracts found in the Defense & Aerospace Competitive Intelligence Service (DACIS) contracts records. This table lists the contract scope, the contract number, contract type, total obligated amount (as of early 2014), start date, current end date, the contractor, and the contractor location. In addition, the study team presents Sand charts showing annual, cumulative costs for current high-dollar (program) contracts. The report summarizes activity and scope of work of ongoing contracts in sequence, along with accompanying graphics showing contract cumulative obligated cost over time.

7. **Operation & Sustainment History**

   This section of the report briefly describes the vehicle sustainment history, and historical changes in military climate and strategy that influenced how the Army operates. The bulk of the chapter is dedicated to tables of O&S costs. Operating and Support (O&S) costs are displayed aligned by OSD CAPE O&S cost element structure. For each variant, the top 10 Consumables and Reparables are tabulated as extracted from the Operating

and Support Management Information System (OSMIS). (OSMIS is the core of the Army Visibility and Management of Operating and Support Costs (VAMOSC) program.)

8. **Operation & Sustainment Status**
   Chapter eight varies among the VRB set; some books include a narrative of sustainment objectives and sustainment management plans. Most VRBs include a table showing O&S Costs in Relation to the Total Life Cycle Cost. Most VRBs also provide summary tables from the DAES reporting on sustainment criteria, such as Materiel Availability, Mean Down Time, and Ownership Costs.

9. **Schedule Milestones**
   Chapter nine shows the major schedule milestones for the program extracted from the latest SAR. Some VRBs also include Gantt charts of the current and future work of development and production efforts.

10. **Cost Data Status**
    The cost data status is communicated via a series of tables of contracts, DCARC CSDR reports and WTV ACDB holdings. The contracts table is an expansion of recent contracts identified in Chapter six, here including tracking of contract modifications and dollar values over time. Tables are included showing number of CDSR, Contract, CPR, and FCHR for the system names related to Bradley housed in the WTV ACDB, sorted by variant. No proprietary cost data from the CSDR, CPR, or FCHR is provided.

11. **Cost Estimating Status**
    Table shows studies available at ODASA-CE pertaining to the Bradley program or that contain relevant cost estimating relationships. Tables provide study title, date, name of performing organization, name of customer, and very short description of the report. Additional tables list other official documents and GAO reports relating to the subject system in a given VRB.

- **References**
  List sources used to prepare the VRB.

2.5.2. DESCRIPTION OF CERS

The report does not contain any CERs.

2.5.3. STRENGTHS AND WEAKNESSES

The VRBs include a wealth of varied programmatic, technical, performance, and cost information and pull data and information from dozens of sources. Such reference books serve as a good first stop for ground vehicle cost analysts to gain a quick, broad education on a given vehicle system. While there are no CERs or even specific cost data to enable CER development,

the books provide large amounts of contextual information to enable an analyst to target data collection and subsequently build data sets and develop CERs.

A weakness is the limited distribution statement posted, "Distribution of the VRB is only permitted to cost analysts in ODASA-CE and TACOM."

2.6. "ANALYSIS OF TECHNICAL DATA PACKAGES", TECHNOMICS, INC., 2014

Program Managers consider the advantages of purchasing Technical Data Packages (TDPs) to support production and support competition. In order to perform informative, useful Cost Benefit Analyses (CBAs) of following through with such an acquisition strategy, the cost community requires cost data for buying TDPs to help estimate the cost of future TDPs. The purpose of this study is to define the terms associated with TDPs, locate data that would support cost estimation in this area, and identify any methods that may be useful in estimating these costs.

The report provides a two page description of a TDP as defined in Military Standard 31000A (MIL-STD-31000A). In summary, a TDP is a technical description of an item adequate for supporting an acquisition, production, engineering, and logistics support. It continues, describing the three levels of detail that TDPs, including: Conceptual, Developmental, and Production.

2.6.1. DESCRIPTION OF DATASET

The study team searched through the contracts and Cost Data Summary Reports (CDSRs) for Abrams, Bradley, Light Armored Vehicle, Stryker and FMTV, held discussions with program office personnel, and searched the Wheeled and Tracked Vehicle (WTV) Automated Cost Database (ACDB) for costs mapped to the Data WBS Element 1.6.2 (Engineering Data).

In summary, the research team did not find significant TDP cost data.

2.6.2. DESCRIPTION OF CERS

No CERs or other estimating methodology was produced.

2.6.3. STRENGTHS AND WEAKNESSES

The study team did not collect cost data for acquiring ground vehicle TDPs, and subsequently was unable to produce cost estimating methodology.

The study did provide a succinct, well-organized description of TDP and gave context to TDP among other data deliverables from contractors.

2.7. "ANALYSIS OF SYSTEM MODIFICATIONS", TECHNOMICS, INC., 2014

The objective of this study was threefold:

- Define the terms associated with vehicle modifications;
- Locate any previously untapped data that would support cost estimation in this area; and
- Develop CERs, if possible.

The study provides formal definitions for "modification" and other terms that are often confused, including: RESET, Reset, Replace, Recapitalize (Recap), Reconstitute, Revitalize, Remanufacture, Retrofit, and Upgrade.

This study was not formally documented in a report, but rather summarized in a short, 11-slide Power Point presentation.

2.7.1. DESCRIPTION OF DATASET

No dataset was prepared in this study.

2.7.2. DESCRIPTION OF CERS

No CERs were prepared in this study.

2.7.3. STRENGTHS AND WEAKNESSES

The body of work has a couple strengths and one significant weakness:

Programs and potential data sources are identified, and formal definitions of various types of vehicle modifications are provided, however no data was collected and no cost estimating methodology was developed. A slide is dedicated to future work, but none has been conducted since.

The presentation refers the reader to a previous study from 2009 titled "The Effects of Requirements Creep on the Costs of Ground Vehicle Systems."

2.8. "CONSUMABLES & REPARABLES COST ESTIMATING", TECHNOMICS, INC., ORIGINAL 2008, UPDATED IN 2012 AND 2013

The original purpose of this work in 2008 was to develop a Cost Estimating Relationship (CER) to estimate costs for Consumables and Reparables (Cons & Reps) (peacetime) incurred by wheeled ground vehicle during the Operations & Support (O&S) Phase. The Army Cost Element Structure (CES) captures these costs in CES "5.03 Replenishment Depot-level Reparables (Spares)" and "5.04 Replenishment Consumables (Repair Parts)."

The 2012 update to the study expanded the underlying dataset and included an Excel-based tool with a user interface to filter data samples and generate data views and CERs quickly.

The 2013 update further expanded the dataset and improved tool functionality, including:

- Incorporated dropdown for user to select one of the following MACOM units (Active only, Reserves only, National Guard only, TRADOC training only, Other only, All)
- Included option for user to obtain annual Cons & Reps data or 10 year averages
- User may now input graphical constraints on the x- and y-axes

2.8.1. DESCRIPTION OF DATASET

There are three fundamental types of data underlying the Consumables & Reparables Cost Estimating dataset and analysis tool. These include: normalized Cons & Reps costs (cost per mile in constant year dollars), vehicle Average Unit Price (AUP), and vehicle reliability metrics (including Mean Miles Between Non-Mission Capable [repair] Visit (MMBNMCV), a proxy for

Mean Miles Between Operational Mission Failure (MMBOMF) and Mean Miles Between System Abort (MMBSA).

The original 2008 work leveraged normalized Cons & Reps costs and activity (miles) from the Army's Operating and Support Management Information System (OSMIS). OSMIS is the Army's Visibility and Management of Operating and Support Costs program. Vehicle AUP was collected from several different sources, including program offices and Cost and Software Data Reports (CSDRs), and Army Master Data File (AMDF) pricing. Vehicle reliability metrics were collected from several different sources including program offices. Table 2.16 identifies systems included.

Table 2.16: 2008 Cons & Reps Study of Wheeled Vehicles

Model	System Series
M1083A1	Medium Tactical Vehicle (MTV)
M1078A1	Light Medium Tactical Vehicle (LMTV)
M1097A2	High Mobility Multipurpose Wheeled Vehicle (HMMWV)
M1113	High Mobility Multipurpose Wheeled Vehicle (HMMWV)
M1126	Stryker

The 2012 update established more consistency and traceability of underlying data and data sources, and expanded the data set.

- Vehicle AUP data all came from the Wheeled and Tracked Vehicle (WTV) Automated Cost Database (ACDB). All raw data records pertaining to selected systems were exported and analyzed, including 198 total records spanning 12 different wheeled systems.

- The Cons & Reps cost data, activity, and reliability metrics all came from Army Material Systems Analysis Agency (AMSAA) Sample Data Collection (SDC) system. The AMSAA data set included 565 records (rows) with 105 different type/model/series vehicles, spanning 1993 through 2012. (A parallel comparative analysis was performed using Cons & Reps cost data and activity from Army OSMIS.) The sample size was reduced to include systems that comprised top 90% of total vehicles in terms of vehicle quantity, and include systems that comprised top

90% of total miles. After applying rules to SDC data, 35 models remained. Eleven out of 35 models also had data from WTV ACDB and OSMIS. Based on the overlap of reliability, AUP, and Cons & Reps data, CERs were developed using the eleven models shown in Table 2.17.

Table 2.17: 2012 Cons & Reps Study of Wheeled Vehicles

Model	System Series
M997	High Mobility Multipurpose Wheeled Vehicle (HMMWV)
M998	High Mobility Multipurpose Wheeled Vehicle (HMMWV)
M1025	High Mobility Multipurpose Wheeled Vehicle (HMMWV)
M1026	High Mobility Multipurpose Wheeled Vehicle (HMMWV)
M1038	High Mobility Multipurpose Wheeled Vehicle (HMMWV)
M1114	High Mobility Multipurpose Wheeled Vehicle (HMMWV)
M1078A1	Family of Medium Tactical Vehicles (FMTV)
M1083A1	Family of Medium Tactical Vehicles (FMTV)
M1088A1	Family of Medium Tactical Vehicles (FMTV)
M977	Heavy Expanded Mobility Tactical Truck (HEMTT)
M1070	Heavy Equipment Transporter (HET)

The 2013 update added a year of Cons & Reps cost history, added more systems, and further improved tool functionality.

- Vehicle AUP data all came from the Wheeled and Tracked Vehicle (WTV) Automated Cost Database (ACDB). All raw data records pertaining to selected systems were exported and analyzed, including 561 total records spanning 48 different wheeled systems.

- The Cons & Reps reliability metrics came from the AMSAA SDC system. (AMSAA SDC Cons & Reps costs were not used.). The AMSAA data set included 116 different type/model/series vehicles, spanning 1990 through 2013

- OSMIS provided vehicle Cons & Reps costs data, spanning 2003 through 2012. OSMIS also provided vehicle inventory (quantity count) and activity (mileage). Data from 93 different vehicles were used.

- The sample size reduced to include systems that comprised top 95% of total vehicles in terms of vehicle quantity, and include systems that comprised top 95% of total miles. After applying filtering rules, and checking for overlap of systems having AUP, reliability, and Cons & Reps data, 49 vehicles (across ten series) were used in CER development. (Documentation may be in error given AUP for only 48 vehicles were pulled from ACDB.)

Table 2.18: 2013 Cons & Reps Study of Wheeled Vehicles

Model	System Series
M998	High Mobility Multipurpose Wheeled Vehicle (HMMWV)
M1025	High Mobility Multipurpose Wheeled Vehicle (HMMWV)
M1097A2	High Mobility Multipurpose Wheeled Vehicle (HMMWV)
M1114	High Mobility Multipurpose Wheeled Vehicle (HMMWV)
M997-2274	High Mobility Multipurpose Wheeled Vehicle (HMMWV)
M1113	High Mobility Multipurpose Wheeled Vehicle (HMMWV)
M1038	High Mobility Multipurpose Wheeled Vehicle (HMMWV)
M1037	High Mobility Multipurpose Wheeled Vehicle (HMMWV)
M1026	High Mobility Multipurpose Wheeled Vehicle (HMMWV)
M966	High Mobility Multipurpose Wheeled Vehicle (HMMWV)
M1025A2	High Mobility Multipurpose Wheeled Vehicle (HMMWV)
M1152	High Mobility Multipurpose Wheeled Vehicle (HMMWV)
M1078A1-6343	Family of Medium Tactical Vehicle (FMTV)
M1083A1-3890	Family of Medium Tactical Vehicle (FMTV)
M1088A1-3893	Family of Medium Tactical Vehicle (FMTV)
M1078A1P2-8577	Family of Medium Tactical Vehicle (FMTV)
M1083A1P2-8610	Family of Medium Tactical Vehicle (FMTV)
M1088A1P2-7759	Family of Medium Tactical Vehicle (FMTV)
M1078A1-3888	Family of Medium Tactical Vehicle (FMTV)
M1083A1-3884	Family of Medium Tactical Vehicle (FMTV)
M1089A1-3892	Family of Medium Tactical Vehicle (FMTV)
M1078A1P2	Family of Medium Tactical Vehicle (FMTV)
M35A2-1617	M35
M35A2C-0873	M35
M923A2	M939
M923	M939
M931A2	M939
M931	M939

M925	M939
M925A2	M939
M929A2	M939
M929	M939
M915A3-4847	M939
M915A1	M939
M915A2	M939
M915	M939
M920	M939
M978-7672	Heavy Expanded Mobility Tactical Truck (HEMTT)
M984A1	Heavy Expanded Mobility Tactical Truck (HEMTT)
M977-6426	Heavy Expanded Mobility Tactical Truck (HEMTT)
M985-7673	Heavy Expanded Mobility Tactical Truck (HEMTT)
M978A2-8215	Heavy Expanded Mobility Tactical Truck (HEMTT)
M977-0260	Heavy Expanded Mobility Tactical Truck (HEMTT)
M984A2	Heavy Expanded Mobility Tactical Truck (HEMTT)
M1075	Palletized Load System (PLS)
M1074	Palletized Load System (PLS)
M818-8984	M809
M813A1-8913	M809

2.8.2. DESCRIPTION OF CERS

The 2008 study presented two CERs, both in the Power functional form:

Cons & Reps $ per mile/AUP$= f (MMBSA)

where:

Cons & Reps $ per mile/AUP$ = ratio of average consumable and reparable costs per mile relative to vehicle average unit procurement price

MMBSA = mean miles between system abort

Cons & Reps $ per mile = *f* (MMBSA, AUP$)

where:

Cons & Reps $ per mile = ratio of average consumable and reparable costs per mile
MMBSA = mean miles between system abort
AUP$ = vehicle average unit procurement price

The 2012 study and analysis tool included a dataset and automated spreadsheets built to allow the user to select/deselect vehicle system(s), visually display graphics, and run regressions. Three CERs were demonstrated of various functional forms, including: Linear, Power, and Logarithmic. Each equation included the same dependent and independent variables.

Cons & Reps $ per mile/AUP$= *f* (MMBNMCV)

where:

Cons & Reps $ per mile/AUP$ = ratio of average consumable and reparable costs per mile relative to vehicle average unit procurement price
MMBNMCV = mean miles between non-mission capable visit

The 2013 study and analysis tool included an enhanced dataset and automated spreadsheets built to allow the user to select/deselect vehicle system(s), visually display graphics, and run regressions. The tool enables three functional forms, including: Linear, Power, and Logarithmic, drawing upon several formulations.

Single independent variable case:

Cons & Reps $ per mile/AUP$= *f* (MMBNMCV)

where:

Cons & Reps $ per mile/AUP$ = ratio of average consumable and reparable costs per mile relative to vehicle average unit procurement price
MMBNMCV = mean miles between non-mission capable visit

Two independent variables case:

Cons & Reps $ per mile = *f* (MMBNMCV, AUP)

where:

Cons & Reps $ per mile = ratio of average consumable and reparable costs per mile

AUP$ = vehicle average unit procurement price

MMBNMCV = mean miles between non-mission capable visit

Three independent variables case:

Cons & Reps $ per mile = *f* (MMBNMCV, AUP, Miles)

where:

Cons & Reps $ = annual consumable and reparable costs
AUP$ = vehicle average unit procurement price
MMBNMCV = mean miles between non-mission capable visit
Miles = annual miles driven

The tool allows for generating CERs for Cons, and CERs for Reps distinct from each using the same basic forms described above. The tool also allows for generating CERs for Cons & Reps costs for each organization separately or in total (Active, Reserve, National Guard, training, other, all).

2.8.3. STRENGTHS AND WEAKNESSES

The 2008 work improved upon previous cost estimating methodology for Cons & Reps. Prior to the 2008 work, Cons & Reps costs were typically estimated using a cost factor applied to vehicle AUP. The strength of the 2008 work is that it added a parameter accounting for reliability, reflecting lower Cons & Reps costs for more reliable systems relative to less reliable systems, given the similar AUPs. A weakness of the work is small dataset and inconsistent data sources (leading to possible dissimilar measures).

The main strength behind the 2012 study and tool is the enhanced dataset and CER automation, allowing for data to be included or excluded with a check box. The tool allows for filtering the data across a variety of parameters, allowing the user to focus on the most applicable subset. Its main weakness is an inconsistency between the Cons & Reps costs reported in SDC and OSMIS; this is not necessarily a weakness in the study, but more a weakness or difference in data collection and reporting systems.

The 2103 study and tool build upon 2012 data set and tool functionality. SDC data has been dropped. The OSMIS data reflects higher variability than SDC data, and yields CERs with weaker statistics.

2.9. "UNCERTAINTY AROUND CONTRACT COST RATES", TECHNOMICS, INC., ORIGINAL 2012, UPDATED 2013

The purpose of this work was to prepare a searchable database and tool to quantify statistical variance of (calculated) contractor rates specific to the Wheeled and Tracked Vehicle industry. Rates are categorized in accordance with DD Form 1921-1 Functional Cost-Hour Reports to include direct labor rates for each functional group (engineering, quality control, tooling, and manufacturing), and indirect overhead rates for each functional group (engineering, quality control, tooling, manufacturing) and material). The tool also provides calculated burdened rates, combing the direct labor and applicable indirect overhead. In addition, the tool hosts summary contract data from DD Form 1921 Cost Summary Data Report to include (calculated) G&A and fee rates. (These rates are calculated values based on the elements within cost reports; the cost reports do not publish rates.)

The tool can provide rates across the industry and allows filtering by program name, contractor name, lifecycle phase, and geographic location for more specific rates metrics. Among rates metrics are: sample size ("count"), mean, standard deviation, coefficient of variation, median, and percentiles (5, 25, 75, and 95). The tool includes a variety of graphics allowing for visualization of data as well as comparative analysis.

The tool also provides summary contextual programmatic information for each program having rate data.

2.9.1. DESCRIPTION OF DATASET

The study team pulled cost data from the Army's WTV Automated Cost Data Base (ACDB). The data records used originated from contractor Cost and Software Data Reports (CSDRs), specifically two formats noted above: DD Form 1921 Cost Summary Data Reports and DD Form 1921-1 Functional Cost-Hour Cost Reports. The Contract Cost Rates tool is populated with over 400 records, across the following nine tracked vehicle programs and five wheeled vehicle programs as shown in Table 2.19.

Table 2.19: Contract Cost Rates Wheeled and Tracked Vehicle Programs

Tracked Vehicle Programs	Wheeled Vehicle Programs
1. M1 Abrams Main Battle Tank (MBT) Series	1. Family of Medium Tactical Vehicles (FMTV) Series
2. Amphibious Assault Vehicle (AAV)	2. Joint Light Tactical Vehicle (JLTV) FoV
3. M2/M3 Bradley Fighting Vehicle (BFV)	3. M939 Series
4. Brigade Combat Team Modernization (BCTM)	4. Mine Resistant Ambush Protected (MRAP)
5. Expeditionary Fighting Vehicle (EFV)	5. Stryker Family of Vehicles
6. Future Combat Systems (FCS)	
7. M113 Family of Vehicles	
8. M48 Main Battle Tank (MBT) Series	
9. XM8 Armored Gun System	

2.9.2. DESCRIPTION OF CERS

The Contract Cost Rates tool includes a backbone dataset of cost and calculated rates, but does not include CERs. The tool and output contractor rates can be used to help convert labor hour estimates into cost estimates, as well as build from cost to price via G&A and fee rates.

A complete listing of rates includes:

- Direct labor
  - Engineering direct labor rates
  - Quality Control direct labor rates
  - Tooling direct labor rates
  - Manufacturing direct labor rates
- Overhead
  - Engineering overhead rates
  - Quality Control overhead rates
  - Tooling overhead rates
  - Manufacturing overhead rates
  - Material overhead rates
- Burdened rates (reflecting direct labor compounded with overhead)
  - Engineering burdened rates
  - Quality Control burdened rates
  - Tooling burdened rates
  - Manufacturing burdened rates
- G&A rates
- Profit/fee rates

2.9.3. STRENGTHS AND WEAKNESSES

A significant strength of the study is the relatively large dataset underpinning its calculations. The data set reflects all available DD Form 1921 Cost Summary Data Reports and DD Form

1921-1 Functional Cost-Hour Cost Reports house in the OSD Defense Cost and Resource Center (DCRAC) as of the date of the product (August 2013). Annual updates are planned.

The tool allows for filtering the data across a variety of parameters, allowing the user to focus on the most applicable subset.

The variance metrics support cost risk analysis.

2.10. "LEARNING CURVE STEP-DOWN ANALYSIS – ABRAMS MAIN BATTLE TANK AND BRADLEY FIGHTING VEHICLE", TECHNOMICS, INC., 2012

The purpose of this study was to examine the relationship between prototype and production recurring costs, and in so doing, the report documents learning curves for two combat vehicles, Abrams Main Battle Tank (MBT) and Bradley Fighting Vehicle (BFV).

This study differs from most other Step-Down analyses in that it explored the impact of using various measures of production cost as the reference point for calculating a step factor. Specifically, the study looked at alternatives to the usual Production T1 as the production reference point and analyzed statistical results when using first lost average unit cost or T1000 as the production reference point. The goal was to identify a preferred method for calculating step factors that reduces variability when comparing step-factors across multiple programs.

2.10.1. DESCRIPTION OF DATASET

The data set used was limited to two combat ground vehicle programs, Abrams MBT and BFV. As of 2014, these are the only two vehicle programs for which development (EMD/FSD) cost history and production lot cost data are available to derive development prototype costs and calculate production learning curves.

Development Phase cost data -

Historical Abrams MBT development cost and hour data were obtained from two sources: (1) Cost and Software Data Reports (CSDRs) from Chrysler in the form of Functional Cost-Hour Report (FCHR) as of 12/31/1979, and (2) a technical report published by TACOM titled "Evaluation and Classification of M1 Tank System R&D Costs", dated May 1982.

Historical BFV development cost data were taken from prime contractor (FMC) Cost Performance Reports (CPR) Format 1 as of July, 1982, when the contract was 99% completed. The CPR does not break costs into recurring and nonrecurring costs. The mapped raw data from the Bradley development contract CPR needed to be normalized to isolate (recurring) prototype manufacturing costs from (nonrecurring) design engineering and tooling. The normalization of recurring hardware costs was done by using Abrams MBT development data to develop factors, by WBS, which were then applied to the FMC CPR data to isolate prototype manufacturing costs.

The study displays hardware development cost data for the two programs generally following MIL-STD-881 WBS as shown in Table 2.20. Since these programs reported cost thru the 1980s, the contractors followed that older version of -881 that was relevant at the time.

Table 2.20: Combat Vehicle Development Phase Cost Data

DEVELOPMENT	Abrams MBT	BFV
Primary Vehicle		
Hull/Frame	X	X
Suspension/Steering	X	X
Power Package/Drive Train	X	X
Auxiliary Automotive	X	X
Turret Assembly	X	X
Fire Control	X	X
Armament		
Body/Cab		
Automatic Loading		
Automatic/Remote Piloting		
Nuclear, Biological, Chemical		
Special Equipment	X	X
Navigation		
Communications		
Primary Vehicle Application Software		
Primary Vehicle System Software		
Vetronics		
Integration, Assembly, Test & Checkout	X	X

Production Phase cost data -

Historical Abrams MBT production costs (full-up vehicle) and quantities spanning 1980 through 1990 were taken from an Abrams Program Management Office data table (dated 1994). Costs were normalized to FY01 using the WTCV indices. The early years of production (1980-1982) were exclusive to the base model, M1. In 1983 and 1984 the production runs included an improved tank named IPM1 with minor improvements with internal automotive, electronics and armor. Production of the upgraded variant M1A1 started in 1984. Tables are provided for production quantity and unit cost of each, but not lower level WBS data.

Historical BFV production cost data came from both CSDRs and CPRs, depending on availability for each lot. According to the report, the CPR data provided the most complete costs-to-date on a lot-by-lot basis; therefore, CPR data was used as a base, with adjustments based on information gleaned from the CSDRs regarding recurring/nonrecurring splits, and considerations for G&A, COM, profit/fee and MR. In addition, lots 3 through 5 had several subsystems acquired outside of the Bradley prime contract as GFE, and those costs do not appear contractor cost reports. In order to ensure all recurring costs of all-up vehicles were accounted for, costs for these GFE subsystems were added to the Bradley prime contractor costs. Cost data for lots 6 through 10 were not used in this study due to issues with subcontractor reporting, and these later lots included A1 and A2 upgrades.

In addition to the BFV production cost data, lot quantities were normalized for learning curve analysis since the BFV and the Multiple Launch Rocket System (MLRS) vehicles were produced concurrently and share approximately 50% commonality.

Tables are provided for production lot quantity and unit cost, but not lower level WBS data.

2.10.2. DESCRIPTION OF CERS

Two types of cost improvement curves were developed using Abrams MBT and BFV production lot data, first using a Unit Learning Curve with learning only, and second using a Unit Learning Curve with both rate and learning terms.

Several Development-to-Production step-down factors were developed, including:

- Prototype AUC / T1
- Prototype AUC / T1000
- Prototype AUC / Actual Lot 1 AUC
- Prototype AUC / Estimated Lot AUC

And several more with Rate term included with learning:

- Prototype AUC / T1 R1
- Prototype AUC / T1000R1
- Prototype AUC / Actual Lot 1 AUC
- Prototype AUC / Estimated Lot AUC (using T1R1)

2.10.3. STRENGTHS AND WEAKNESSES

A significant strength of the study is that it explores a unique perspective on calculating Development-to-Production step-down factors, and uncovers a potentially useful finding. The variation in step-down factors is significantly reduced when considering prototype AUC to T1000. This is likely due to the flattening of learning and rate effects as production matures. In contrast, the traditional method of stepping to production T1 suffers from volatile impacts of the learning curve extrapolating to unit #1.

For each Learning Curve regression, complete CO$TAT output is provided in the appendices, including: Coefficient Statistics Summary, Goodness of fit statistics, and ANOVA tables, among others.

A weakness of the report is lack of data, with only two programs. More study is required on additional programs before this method can be stated as a firm, universal conclusion. Additionally, a weakness may be that a rate curve parameter was not addressed.

2.11. "2011-2012 UPDATE TO: ARMY GROUND VEHICLE SYSTEMS BLUEBOOK/SUFFICIENCY BOOK", TECHNOMICS, INC., 2012

The Bluebook/Sufficiency Book presents result from cost research, providing several key cost estimating methodologies to support cost analysts in preparing ground vehicle cost estimates, including: learning curve analysis, development-to-production step functions, hardware cost-to-cost factors, hardware Cost Estimating Relationships (CER) and Cost Performance Estimating Relationships (CPER), and Below-The-Line (BTL) contractor support cost factors. Each topic has a dedicated chapter, with backup information and data provided in the appendices; however, some appendices include a summary narrative with references to previously delivered documents

to the Army customer, ODASA-CE. A summary table of cost analysis is presented in Table 2.21.

Table 2.21: Cost Analysis Summary

Cost Analysis	Development	Production
Learning Curve		**X**
Development-to-Production Step Factors	**X**	**X**
Hardware Cost to Cost Factors	**X**	**X**
Hardware CER/CPER		**X**
Below-the-Line (BTL) Contractor Support Factors	**X**	**X**
BTL Factors by Lot Number		**X**

2.11.1. DESCRIPTION OF DATASET

The primary data source for this study is the Wheeled and Tracked Vehicle Automated Cost Data Base (WTVACDB). This analysis also draws heavily upon previously conducted studies and analyses:

- Ground Vehicles Integrated Performance Cost Model
- Ground Vehicles Power Train Methodology Development
- Non-Manufacturing Cost Estimating Factors
- High Powered Engine Analysis
- Step Down Functions for Abrams Main Battle Tank and Bradley Fighting Vehicle
- Bradley Cost Per Pound Per WBS Element Study

Learning Curve Analysis - At the time the study was written, available data suitable for learning curve analysis (at WBS level 3) was limited to the Bradley Fighting Vehicle (BFV) program. Additional data was used from the Abrams Main Battle Tank (MBT) program to supplement the Transmission learning curve analysis. The WBS followed in the analysis is displayed in Table 2.22.

Table 2.22: Learning Curve Data Availability

WBS Element	BFV	Abrams MBT
Hull/Frame	X	
Suspension	X	
Power Package/Drive Train	X	
Engine	X	
Transmission	X	X
Other PP/DT	X	
Auxiliary Automotive	X	
Turret Assembly	X	
Fire Control	X	
Integration & Assembly	X	

Most of the BFV cost data was obtained from Contract Cost Data Reports (CCDRs). The study authors filled in gaps using contract data.

Step-Factor Analysis – Both development and production data from the BFV program were used. See Table 2.22 for WBS. The source data for development costs was not identified, but data is shown in Appendix D of the report.

Hardware Cost-to-Cost Factors – these factors relate the cost of individual hardware WBS elements to total hardware costs. Data sufficient to develop production factors is available only for the BFV, using the first ten years of production data. Using this data, factors are developed for the WBS elements Hull/Frame, Suspension, Auxiliary Automotive, Turret, and Integration and Assembly (I&A).

Hardware CER/CPER – The document includes a subsection on cost relationships, each developed at Level 3 of the WBS or lower (i.e., Level 4 under Power Pack/Drive Train). For each CER, the systems are identified, however the source of the cost data (and technical and performance data) are not clearly identified. The data used in each CER is provided in Appendix G of the report. Table 2.23 provides an overview of systems included in each subsystem CER, with T= tracked, W = wheeled.

Table 2.23 – Subsystem CER Datasets

WBS Element / Vehicle System	M2/M3 Bradley Fighting Vehicle (BFV) T	M2/M3 A1 T	M2/M3 A2 T	M2/M3 A3 T	M993 Multiple Launched Rocket System (MLRS) T	M1 Abrams Main Battle Tank (MBT) T	Stryker (excl MGS & NBCRV) vehicles W	Stryker Mobile Gun System (MGS) W	Stryker Anti-Tank Guided Missile (ATGM) vehicle W	Stryker Infantry Carrier (ICV) vehicle W	M8 Armored Gun System (AGS) T	M109 series Self-propelled Howitzer T	M113 A1/A2 Amored Personnel Carrier (APC) T	M113A3 APC T	Engine DDC/MTU 4L890 S	Engine DDC/MTU 6V890 S	M9 Armored Combat Earthmover (ACE) T	M88A1 Armored Recovery Vehicle (ARV) T
Hull/Frame	X	X	X		X		X	X			X							
Suspension	X				X	X	X	X			X							
Engine	X	X	X	X								X	X	X	X	X		
Transmission	X	X											X	X			X	X
Auxiiary Automotive	X				X	X	X	X			X							
Turret, FC, & Armament	X	X			X			X	X	X	X							
Integration & Assembly	X	X	X		X	X	X	X			X							

Key:
T = Tracked vehicle
W = Wheeled vehicle
S = Subsystem

Below The Line (BTL) Cost Factors – The document includes a subsection on factors which may be used to estimate the cost of non-manufacturing elements of vehicle development and production. **[This work is superseded by a study called "Below-the-Line Factors for Wheeled and Tracked Vehicles", sponsored by Office of the Deputy Assistant Secretary of the Army for Cost and Economics, prepared by Technomics, Inc., Original March 31, 2014, Revision September 31, 2014]** This study was reviewed and summarized earlier in this document.

Cost Performance Report (CPR) is the source for most of the systems analyzed. Costs from CPR were broken down by WBS, but in most cases there is insufficient breakout between Development Engineering and Prototype Manufacturing. Functional Cost Hour Report (FCHR)

data, broken down by detailed WBS and CES structures, is only available for a limited number of systems.

Table 2.24 – Development Phase Cost Factors Vehicle Programs

Tracked Vehicles	Wheeled Vehicles
Abrams FOV Main Battle Tank (Abrams)	Light Armored Vehicle (LAV) system
Advanced Amphibious Assault Vehicle (AAAV)	Medium Tactical Truck Remanufacture (MTTR)
Advanced Field Artillery System (AFAS)	Stryker
Amphibious Assault Vehicle (AAV)	XM93E1 FOX NBCRS
Armored Gun System (AGS)	
Bradley Fighting Vehicle (BFV)	
Bradley Fire Support Team (BFIST) vehicle	
Command and Control Vehicle (C2V)	
Composite Armored Vehicle (CAV)	
Crusader	
Grizzly Combat Mobility Vehicle (Grizzly)	
Heavy Dry Support Bridge (HDSB)	
M109 FOV Ammunition Support Vehicle (FAASV)	
M88 Armored Recovery Vehicle (ARV)	
Wolverine Heavy Assault Bridge (Wolverine)	

Production phase cost-to-cost factors are computed using data from the BFV program (spanning M2/M3, M2A1/M3A1, and M2A2/M3A3 variants); the BFV production program reported vehicle Contractor Cost Data Reports across ten consecutive years. This allowed calculation, graphical depiction, and examination of factors over time.

2.11.2. DESCRIPTION OF CERS

Each analysis area is summarized in the same order as presented in the report and described in the previous section of this literature review summary, *Description of Dataset.*

Learning Curve Analysis - The study provides regression analysis following unit theory learning, with and without rate effects. Analysis was performed for each of the WBS elements documented in Table 2.22. The study indicates, however, that modeling learning with rate does

not yield useful results, at least on the available dataset. Data and CO$TAT learning curve output is provided in the study's Appendix C.

Step-Factor Analysis – The relationship between the first unit cost of a development vehicle and the first unit cost of a production vehicle was explored, with analysis of BFV WBS Level 3 hardware.

The report states that "*additional data, were it available, could smooth out anomalies inherent in individual programs. Therefore, these factors should be used primarily as secondary estimation techniques to verify or confirm analysis supported by more robust data set*." Detailed computations and results of the step function analysis can be found in Appendix D of the report.

Hardware Cost-to-Cost Factors – Hardware Cost-to-Cost Factors relate the cost of individual hardware WBS elements to total hardware costs. Using ten years of BFV data, Lot Average, Lot Median, and Dollar Weighted Average factors are developed for the Level 3 WBS elements.

Data tables and line graphs are included in the report showing the lot-by-lot factor across all ten lots.

Hardware CER/CPER – The document includes a subsection on cost relationships, each developed for major hardware subassemblies:

Hull and Frame CPER (ref. page G-5)

Unit100 = *f* (CW, Aluminum, Turret)

where:

Unit100 = 100th unit cost
CW = Weight of the vehicle in tons
Aluminum = 1 if aluminum is the primary material of the vehicle
Turret = 1 if vehicle is equipped with a turret

Suspension CPER (ref. page G-12)

UC100 = *f* (CWSpdRat, Wheel)

where:

UC100: 100th unit cost
CWSpdRat: ratio of combat weight (tons) to speed (mph)
Wheel: Dummy = 1 if vehicle has a wheeled suspension, = 0 if tracked

Engine CPER (ref. page G-33)

Unit_Cost = *f* (PD)

where:

Unit_Cost = Estimated full rate production unit cost in
PD = Engine Power Density (hp/ft3 (engine box))

Transmission CPER (ref. page G-49)

Unit100 = *f* (HP, Spd)

where:

Unit100 = 100th unit cost
HP = Gross Horsepower of engine the paired transmission
Spd = Top highway speed of vehicle transmission installed (mph?)

The study attempted to develop a CPER based solely on the characteristics of the subassembly, in this case, the transmission. As a result of the deficiencies observed and described in the paper, and the resulting inability to develop a credible estimating relationship based on transmission technical and performance characteristics, another approach was tried. This approach used the performance and technical characteristics of the vehicles in which the transmissions are installed as independent variables. The resulting CPER is shown above.

Auxiliary Automotive CPER (ref. page G-53)

UC100 = *f* (Tech, TP)

where:

UC100: 100th unit cost
Tech: Technology level (year of first production - 1900)
TP: Number of crew personnel that reside in the turret

Turret, Fire Control and Armament CPER

Unit100 = *f* (ArmSiz, Fen, ASCWRat, GAP)

where:

Unit100 = 100th unit cost
ASCWRat = Armament Size (mm?) divide by Combat Weight (ton?)
Gap = Gap crossing distance in inches
TOWII = 1 if vehicle is equipped with 2nd generation missile launcher

Integration and Assembly CPER

Unit100 = *f* (ArmSiz, Fen, ASCWRat, GAP)

where:

Unit100 = 100th unit cost
ArmSiz = Armament size in mm
Gen = Vehicle generation
ASCWRat = Armament Size (mm?) divide by Combat Weight (ton?)
Gap = Gap crossing distance in inches

Below The Line (BTL) Cost Factors – The document includes a subsection on factors which may be used to estimate the cost of non-manufacturing elements of vehicle development and production. **[This work is superseded by a study called "Below-the-Line Factors for Wheeled and Tracked Vehicles," prepared by Technomics, Inc., Original March 31, 2014, Revision September 31, 2014.]** This study was reviewed and summarized earlier in this document.

This analysis can provide insight into the possible range of values for each element, as well as a general average of historical programs. However, in certain specific cases, the best approach is

to choose a smaller subset, or in some cases, a single point, that most closely relates to the system being estimated. The data for each system is included in Appendix H of the study.

Two methods of analysis are used to develop cost factors. First, a system-by-system analysis is conducted where the factors for each system were determined separately, with summary statistics then being calculated across all of the individual systems. Second, a program-size weighted analysis sums the cost for each WBS element across all programs, and divides by the total summed program costs.

In addition, three sets of development phase cost actors were provided: 1) Development Engineering used as a base; 2) Prototype Manufacturing used as the base, and 3) because much of the raw data did not separate nonrecurring from recurring, a third set of cost factors were used in which the sum of Development Engineering and Prototype Manufacturing was used as the base.

DEVELOPMENT:

Army cost element cost factors derived using CES 1.01 Development Engineering $ as the base:

- CES 1.02 Producibility Engineering and Planning $ = *f* (CES 1.01 $)
- CES 1.03 Development Tooling $ = *f* (CES 1.01 $)
- CES 1.04 Prototype Manufacturing $ = *f* (CES 1.01 $)
- CES 1.05 Systems Engineering/Program Management $ = *f* (CES 1.01 $)
- CES 1.06 System Test and Evaluation $ = *f* (CES 1.01 $)
- CES 1.07 Training $ = *f* (CES 1.01 $)
- CES 1.08 Data $ = *f* (CES 1.01 $)
- CES 1.09 Support Equipment $ = *f* (CES 1.01 $)

Army cost element cost factors derived using CES 1.04 Prototype Manufacturing $ as the base:

- CES 1.01 Development Engineering $ = *f* (CES 1.04 $)
- CES 1.02 Producibility Engineering and Planning $ = *f* (CES 1.04 $)
- CES 1.03 Development Tooling $ = *f* (CES 1.04 $)
- CES 1.05 Systems Engineering/Program Management $ = *f* (CES 1.04 $)

- CES 1.06 System Test and Evaluation $ = *f* (CES 1.04 $)
- CES 1.07 Training $ = *f* (CES 1.04 $)
- CES 1.08 Data $ = *f* (CES 1.04 $)
- CES 1.09 Support Equipment $ = *f* (CES 1.04 $)

Army cost element cost factors derived using the sum of CES 1.01 Development Engineering $ and CES 1.04 Prototype Manufacturing $ as the base:

- CES 1.02 Producibility Engineering and Planning $ = *f* (CES 1.01 $, CES 1.04 $)
- CES 1.03 Development Tooling $ = *f* (CES 1.01 $, CES 1.04 $)
- CES 1.05 Systems Engineering/Program Management $ = *f* (CES 1.01 $, CES 1.04 $)
- CES 1.06 System Test and Evaluation $ = *f* (CES 1.01 $, CES 1.04 $)
- CES 1.07 Training $ = *f* (CES 1.01 $, CES 1.04 $)
- CES 1.08 Data $ = *f* (CES 1.01 $, CES 1.04 $)
- CES 1.09 Support Equipment $ = *f* (CES 1.01 $, CES 1.04 $)

Production phase cost-to-cost factors were computed using data from one program, the BFV program (spanning M2/M3, M2A1/M3A1, and M2A2/M3A3); it reported data across ten consecutive years. This allowed calculation, graphical depiction, and examination of factors over time.

PRODUCTION:

Army cost element cost factors derived using CES 2.02 Recurring Production $ as the base:

- CES 2.01 Non-Recurring Production $ = *f* (CES 2.02 $, lot number)
- CES 2.04 Systems Engineering/Program Management $ = *f* (CES 2.02 $, lot number)
- CES 2.05 System Test and Evaluation $ = *f* (CES 2.02 $, lot number)
- CES 2.08 Support Equipment $ = *f* (CES 2.02 $, lot number)
- CES 2.10 Fielding $ = *f* (CES 2.02 $, lot number)

2.11.3. STRENGTHS AND WEAKNESSES

The body of work has a couple strengths and three significant weaknesses.

As for strengths, the study covers a variety of key cost estimating methods, making it a first-stop resource to help kick off cost estimating for new programs without their own cost history. Also, data and analysis is provided in the Appendices, allowing users to validate or modify methodologies by adding or removing data points.

A key weakness in the body of work is the limited data sets that span both development and several years of production. This impacts the Learning Curve work, the Step-Down factor analysis, and production cost factor analysis, all limited to a single program, Bradley Fighting Vehicle.

Some of the data is sourced, but not all. The study does a fair job of citing cost data sources, but a weak job identifying technical data references.

On the CPER, some of the input variable units are not clearly identified. By looking at other CPERs in the study, the user can assume the units used.

2.12. "UNMANNED GROUND VEHICLES", TECHNOMICS, INC., 2011

The Unmanned Ground Vehicles (UGV) study touches upon several topics, not directly related to each other, but providing a broad set of technical and cost information. The stated purpose of the study is it "is an ongoing effort to gain insights into the emerging UGV technologies and the costs associated with developing, producing, and operating and supporting the systems." The study is broken up into four chapters addressing cost data and cost estimating, as well as technical data. The first chapter describes and displays UGV parts consumption data analysis of two different systems, and also includes a treatment procurement cost analysis of a third system. The second chapter provides a brief synopsis of program information on eight UGV systems gained from visits to UGV trade shows and UGV Program Office interviews. The third chapter briefly describes emerging technologies as they apply to UGVs. The fourth and final chapter lays out a suggested path forward for future cost research.

2.12.1. DESCRIPTION OF DATASET

Data for this study came in three sets:

- Parts consumption costs data,
- Procurement unit price data,
- Programmatic and technical data from interviews and product brochures

Parts consumption cost data were collected for two UGVs including TALON and PackBot. CONUS consumption data (FY09 through first month FY11) was collected from training courses hosted at Fort Leonard Wood, MO and considered peacetime operations. Annual cost per system was based on parts cost only and does not include man hours associated with repairs. In addition, OCONUS consumption data was collected for the same two UGV systems from the Joint Robot Repair Fielding (JRRF) Catalog Ordering Logistics Tracking System (COLTS), representing in-theater (Afghanistan and Iraq) data (FY06). The following table displays the varying parts breakout for each UGV and data source. For the purposes of this summary, the parts were aligned alphabetically and compared across systems and sources. (Note: there is no MIL-STD-881 WBS for UGVs).

Table 2.25: UGV Consumption Parts Cost Drivers

TALON		**PackBot**	
CONUS	**OCONUS**	**CONUS**	**OCONUS**
Antenna	Antenna	Antenna	Antenna
Arm	Arm	Arm	Arm
Battery	Battery	Battery	Battery
Camera	Camera	Camera	
Operator Control Unit	OCU	OCU	
Pan/Tilt Mast	Pan/Tilt Mast	Pan/Tilt Mast	
PC Board	PC Board	PC Board	
			PCC (?)
Platform		Platform	
Platform Electronics		Platform Electronics	
			Spooler
	Suspension		Suspension
Wrist and Gripper		Wrist and Gripper	
	Other		Other

The study reports that all-up system **procurement unit price data** and replacement part price data were obtained from contract documents for four UGVs, including: M160, SUGV 310, PackBot, and TALON. However, the report displays procurement unit price data and detailed

parts pricing data tables for only one system, TALON, in both raw and mapped formats; the mapping rolled parts to a higher-level, summary WBS. The mapped TALON data was used in CER development, leveraging four variants of that system. The table below shows the WBS for TALON.

Table 2.26: TALON Unit Price WBS

TALON
Miscellaneous ODC
Shipping Only
Communications
Base
Arm
Batteries
Camera
Controller
Gripper

Programmatic and technical data were collected from interviews conducted at several UGV trade shows: narratives were provided in the body of the report, with technical specifications presented in the Appendices by way of company brochures. Technical specifications varied from system to system, and spanned a broad range of physical and performance metrics; too many to list here. Specifications are not entirely the same across manufacturers, nor are they the same across systems. The reader will need to review Appendix III for UGV system-specific programmatic and technical data. These technical specifications and programmatic information are not captured in an electronic database or dataset.

Systems include:

- Small Unmanned Ground Vehicle (SUGV) 310 & 320, by Boeing (prime) and iRobot (subcontractor and producer)
- PackBot 510, by iRobot
- 710 Warrior, by iRobot
- TALON family of UGVs, by QinetiQ
- Multifunction Utility/Logistics and Equipment vehicle (MULE), by Lockheed Martin
- Squad Mission Support System (SMSS), by Lockheed Martin
- Ground Unmanned Support Surrogate (GUSS), by TORC, Virginia Tech, and Marine Corps Warfighting Laboratory (MCWL)

2.12.2. DESCRIPTION OF CERS

Discussion of CERs followed the order of the cost data presentation.

- **Parts consumption** cost estimating methodology was simply addressed with calculated average annual costs for both TALON and Packbot, for both CONUS and OCONUS to enable estimating by analogy. In addition, costs per CONUS work order are provided for both TALON and Packbot.
- **Procurement unit price** for a TALON production system, using cost data from four TALON variants was modeled.

TALON UGV Unit Price = *f* (base $, camera $)

where:

base $ = cost of the basic system assembly

camera $ = cost of the onboard camera

2.12.3. STRENGTHS AND WEAKNESSES

A strength of the study is the detailed parts pricing data obtained for CONUS and OCONUS consumption on two fielded UGV systems, TALON and PackBot. This has the potential to facilitate O&S Phase cost estimating for those two systems or systems of analogous size, mission, and complexity.

A second strength is the breadth and depth of technical and performance specifications documented in the collection of company product brochures that are collected and presented in on place.

The study lacks in robust, cross product lines cost or pricing data. This lack of data, in turn, inhibits robust CER development for estimating UGVs at the all-up system as well as at the major subcomponent level. Technical specifications and programmatic information are not captured in an electronic database or dataset. A cost dataset paired with the technical data would be more useful. In addition, having the product brochure technical and programmatic data recorded in a database or dataset would add utility.

2.13. "THE EFFECTS OF COMPETITION ON THE ACQUISITION COSTS OF GROUND VEHICLE SYSTEMS", TECHNOMICS, INC., 2009

The purpose of this study was to identify the effect of competition during production in DOD procurement, with an emphasis on ground vehicle programs. Several key economic assumptions and variables surrounding competition are addressed, with discussion of those parameters within the DOD acquisition environment. The study describes a four-part approach for competition analysis that includes:

1. a database of the history of major recent US Army vehicle procurement, including both competitive and non-competitive programs
2. a break-even analysis methodology that determines the required cost reduction required to ensure that competition does not result in increased cost
3. an estimate of the likelihood of achieving an estimated cost reduction
4. suggestions for future work

The report uses the Joint Light Tactical Vehicle (JLTV) as an example with sample calculations of #2 and #3 above.

In addition to the report, the study team delivered a modeling tool to aid in determining the effects of competition on future programs.

2.13.1. DESCRIPTION OF DATASET

A cost/technical database is not a component of this study; however, a compilation of sixteen ground vehicle programmatic and acquisition histories are provided in its Appendix A, including:

- High Mobility Multipurpose Wheeled Vehicle (1983-2009)
- Family of Heavy Tactical Vehicles (1990-2009)
- Family of Medium Tactical Vehicles (1991-2009)
- Mine Protection Vehicle Family (2004-2009)
- M1 Abrams Tank and Mod (1981-2009)
- M2/M3 Bradley Fighting Vehicles (1981-2009)
- M88 Recovery Vehicle Series (1978-1989: Conversion of M88s to M88A1s & Production of M88A1s)
- M88 MOD – Convert M88A1 Medium Recovery Vehicle to M88A2 Heavy Equipment Recovery Combat Utility Lift and Evacuation System (1994-2009)

- M109A5 Howitzer, Med SP, FT, 155MM (1992-1997)
- M109A6 Howitzer, Med SP, FT, 155MM (1992-2009)
- M113 Armored Personnel Carrier Mod (1978-2007)
- M1117 Guardian Armored Security Vehicle (1997-2009)
- M915/M916 Truck, Tractor, Line Haul (1978-2009)
- M939 Series Truck, Tractor, 5T 6x6 ABT (1978-1989)
- M992 Fielded Artillery Ammunition Support Vehicle (1983-1998)
- Stryker Series (2002-2009)

2.13.2. DESCRIPTION OF CERS

The principle cost estimating relationship presented in the study underpins the break-even analysis. The report illustrates a three-step approach to performing the break-even analysis:

1. Estimate the expected cost of producing the system by a sole source
2. Estimate the additional cost of introducing a competitor
3. Determine the percentage reduction in sole-source cost that would be required to offset these additional costs

This necessary reduction is referred to as the Required Cost Reduction (RCR); it is calculated using the following equation:

$$RCR = f(TC_1(q1), TC_2(q2), TC_{SS}(Q), INV_C, INV_{SS})$$

where:

TC_1 (q_1) = recurring cost for (competitive) contractor 1 to produce quantity q_1

TC_2 (q_2) = recurring cost for (competitive) contractor 2 to produce quantity q_2

TC_{SS} (Q) = recurring cost of the single-source contractor to produce quantity Q

INV_C = nonrecurring cost required to bring both contractors to full production

INV_{SS} = nonrecurring cost to bring single-source to full production

$Q = q_1 + q_2$

The report provides graphics and analysis of various outcomes of RCR when different assumptions are made about the timing (lot number) of introducing a second source, size of split buys, and other cost-driving assumptions.

2.13.3. STRENGTHS AND WEAKNESSES

The report provides a good economic perspective of the impact upon pricing due to competition, in both the public market (many buyers/many sellers/similar products) and the DOD-specialized market (single buyer/few sellers/complex, unique products).

The report also provides a quantitative means to help cost analysts estimate the dollar impact of competition, and ultimately help program managers make informed decisions about whether to pursue competitive acquisition. The study includes a mathematical example to aid the reader understand the approach.

As a third notable strength, the report includes a useful Appendix synopsizing programmatic and acquisition histories of 16 ground vehicle programs. This may serve as a good starting point for identifying analogies, or continuing further research.

The key weakness of this study is the lack of cost data. Perhaps due to the nature of ground vehicle acquisition and record keeping, there is no cost data to prepare strong modeling of actuals comparing non-competitive strategies to competitive strategies for the same or similar system. Conclusions about impacts due to competition are derived by extrapolation from other DOD commodities, such as Missiles and Ships.

2.14. "MINE RESISTANT AMBUSH PROTECTED (MRAP) CONTRACT PRICE ANALYSIS", TECHNOMICS, INC., 2007

Tactical ground vehicle price analysis was performed in support of the Army and Marine Corps Joint Light Tactical Vehicle (JLTV). Prepared prior to JLTV Milestone A, a cross-check, top-level cost estimating methodology for the Average Unit Price (AUP) was developed.

2.14.1. DESCRIPTION OF DATASET

Data was pulled from a program considered JLTV's closest analogy, the MRAP program. The MRAP program procured different vehicles from different vendors to meet the rapid acquisition call during the Iraq War. The study pooled technical and cost data across all MRAP contracts.

The MRAP program awarded test demonstration contracts to nine different businesses in January of 2007. Manufacturers offered (up to) three Categories (CAT) of vehicle systems, including CAT I, CAT II, and some offered CAT III vehicles. (CAT I and II are similar, with CAT I generally being a shorter 4-wheeled system relative to the longer, CAT II system, generally 6-wheeled. The CAT III is a mine clearing vehicle, and not used in this analysis.) Based on the results of those tests, subsequent options were exercised with seven businesses. The following table displays MRAP contract awards and delivery orders exercised through August 20, 2007.

Table 2.27: MRAP Contract Awards and Delivery Orders Exercised (thru August 20, 2007)

Company Name	Contract Number	No. of Delivery Orders	No. of Vehicles
BAE Systems Land & Armaments	M67854-07-D-5025	3	535
Oshkosh	M67854-07-D-5026	2	104
Protected Vehicles, Inc	M67854-07-D-5027	2	64
General Dynamics Land Systems	M67854-07-D-5028	3	624
General Purpose Vehicle	M67854-07-D-5029	1	4
Stewart & Stevenson	M67854-07-D-5030	2	1,174
Force Protection Industries, Inc	M67854-07-D-5031	5	1,709
International Military & Government LLC	M67854-07-D-5032	4	1,975
Textron Marine & Land Systems	M67854-07-D-5033	1	4

Contract pricing information was obtained from the contracts and delivery order documentation, enabling the study team to segregate the vehicle pricing from support services and equipment by reviewing contract Section B "Supplies or Services." The study states that contract prices used reflect hardware costs and associated systems engineering/program management, based on the types and materials separately priced in other CLINs.

In CER development, the study used a subset of contractors that had multiple delivery orders and substantial quantity. Specifically, data for Textron (one D.O., four units), General Purpose Vehicle (one D.O., four units), and Protected Vehicles Incorporated (PVI) (two D.O., only 64 units) were excluded from analysis, as well as Oshkosh Alpha CAT I vehicle.

Physical and technical data in this study were originally obtained from the MARP CARD dated November 2007, and reproduced in the study in tables. Vehicle specifications include:

- Length
- Width

- Height
- Gross vehicle weight (GVW)
- Curb weight
- Payload weight
- Horsepower

The following list identifies the vehicles used in the analysis, including company and system name.

- FPI (Cougar JERRV 4X4)
- BAE (RG-33)
- GD (RG-31 Mk5)
- Armor Holdings (Caiman I)
- International (CAT I)
- FPI (Cougar 6X6)
- BAE (RG-33L)
- GD (RG-31 Mk5E)
- Oshkosh (Bushmaster)
- Armor Holdings (Caiman II)
- International (CAT II)

2.14.2. DESCRIPTION OF CERS

Data plots were displayed showing Average Unit Price (AUP) versus vehicle weight. Follow-on plots and discussion reveal that there are stronger trends with the rate of change in cost per pound relative the vehicle weight. The report asserts that there are economies of scale in which larger vehicles exhibit a lower cost per pound than smaller vehicles. Two weight-based CERs were presented including:

AUP/lb = *f* (curb wt)

where:

AUP/lb = average unit price in per vehicle curb weight in pounds

curb wt = vehicle curb weight in pounds

AUP/lb = *f* (GVW)

where:

AUP/lb = average unit price in per gross vehicle weight in pounds

GVW = gross vehicle weight in pounds

A second analysis of the data considered mobility performance and vehicle size in terms of horsepower per ton. Again, both curb weight and gross vehicle weight (GVW) we used. Again the study reports better results (improved adjusted R2, F-statistic, and t- statistics) when modeling the rate of change with dollars per HP/Ton as a function of HP/Ton. Two CERs were presented including:

AUP per HP/ton = *f* (HP/ton) *(related to curb weight)*

where:

AUP per HP/ton = average unit price per horsepower per ton curb weight

HP/ton = horsepower per ton curb weight

AUP per HP/ton = *f* (HP/ton) *(related to gross vehicle weight)*

where:

AUP per HP/ton = average unit price per horsepower per ton gross vehicle weight

HP/ton = horsepower per ton gross vehicle weight

The report also discusses the step-ladder pricing data and presents calculated rate slopes for each CAT vehicle for each contractor.

The above CERs were rerun with pricing normalized for rate effect, and it was found that the fit statistics diminished.

2.14.3. STRENGTHS AND WEAKNESSES

A significant strength of the study is the cost estimating approach taken uses a few (generally) known, top-level parameters that are relatively stable pre MS A rather than relying on more detailed specifications that are likely to evolve over the development process.

The pricing data and technical data come from reliable sources.

Given the data all comes from the same class of vehicle with the same mission, the data has limitations in application.

While the statistics of each CER are strong, the relationships are curves. By visual inspection, the data also suggest linear relationships. The nonlinear (curve) CERs can lead to large mis-estimating when moving outside of the relevant range.

2.15. "MARINE CORPS STUDIES PROGRAM SUPPORT - MARINE PERSONNEL CARRIER (MPC) COST AND EFFECTIVENESS ANALYSIS SUPPORT TO THE MPC ANALYSIS OF ALTERNATIVES (AOA)", TECHNOMICS, INC., 2007

From the study abstract, "The Marine Personnel Carrier (MPC) is a United States Marine Corps (USMC) initiative to field a cost-effective armored personnel carrier, balanced in performance, protection and payload for employment within the Ground Combat Element (GCE) and throughout the range of military operations. The primary objective of the MPC Analysis of Alternatives (AoA) is to assist the Milestone Decision Authority (MDA) by rigorously and objectively evaluating the effectiveness, costs, and cost-effectiveness of the classes of alternatives being considered for a MPC."

Six vehicle classes were selected for the alternatives considered in the AoA. The following is a list of the specific alternatives analyzed for each vehicle type:

- Amphibious Assault Vehicle (AAV)
  - Alternative 1: AAV (status quo)
- Light Armored Vehicle (LAV) Generation (Gen) II
  - Alternative 2: Company Model C, LAV Gen II
  - Alternative 3: Company Model A, LAV Gen II
- Heavy Armored Personnel Carrier (APC)
  - Alternative 4: Company Model C, Stryker Next Generation
  - Alternative 5: Company Model A, Stryker Next Generation
- Medium APC
  - Alternative 6: Company Model C, Stryker
  - Alternative 7: Company Model C, Piranha III
  - Alternative 8: Company Model A, Stryker
  - Alternative 9: Company Model A, Piranha III
- Heavy Armored Truck
  - Alternative 10: Company Model C, Cougar Category II
  - Alternative 11: Company Model C, Up-Armored Medium Tactical Vehicle Replacement
- Medium Armored Truck
  - Alternative 12: Company Model C, Bushmaster
  - Alternative 13: Company Model C, Caiman II

This AoA evaluates and compares the alternatives for procuring an MPC and supports a Milestone B decision. The cost estimating portion of the AoA is the focus of this summary review.

2.15.1. DESCRIPTION OF DATASET

Most of the 13 ground vehicle alternatives are based on existing vehicle systems with a few variants requiring additional GFE integration or additional armor on the hull.

Cost estimates are largely based on the available data supplied by the existing program offices. The Study Team collected what it considered the most reliable, highest quality data available to it. The Study Team ranked data pedigree, from high to low as follows:

- Official cost reports delivered to the Government (such as Contractor Cost Data Reports (CCDR) and Cost Performance Reports (CPR)) and internal contractor accounting records as being high quality. These data sources provided insight into the "actual" costs.
- Contract prices of executed contracts, including any post-contract award adjustments. These data, while containing a historical record, mask the profit/loss.

- Yet-to-be executed contracts or quotes and engineering assessments. These sources are estimates themselves.

Given the maturity of the systems, requirements of the AoA alternatives, and limited data, only three programs were cited with development phase data useful to this study: AAV, LAV, and Stryker, all fielded systems. Data from the LAV and AAV programs are from PM estimates and piecemeal actuals of subsystem hardware upgrades and support costs. The Stryker data is from a CCDR. Comprehensive development phase data was not presented. Table 2.28 summarizes the development cost data that was used and shared in the study.

Table 2.29 provides a summary of the production phase cost data. Most of the systems have only vehicle level cost data available. Lower-level subsystem costs are available on the Stryker program, and estimates of subsystem enhancements were made available by participating program offices of AAV and LAV.

Table 2.28: Development Phase Data

DEVELOPMENT	AAV (1)	LAV (2)	Stryker (3)
Primary Vehicle			X
Hull/Frame	est	est	
Power Package/Drive Train	est	est	
Auxiliary Automotive	est	est	
Turret Assembly			
Fire Control			
Armament			
Body/Cab			
Automatic Loading			
Automatic/Remote Piloting			
Nuclear, Biological, Chemical			
Special Equipment			
Navigation			
Communications			
Primary Vehicle Application Software			
Primary Vehicle System Software			
Vetronics	est	est	
Integration, Assembly, Test and C/O			
System Engineering		est	X
Program Management		est	X
System Test and Evaluation		est	X
Training		est	X
Data		est	X
Peculiar Support Equipment		est	
Common Support Equipment			
Operational/Site Activation			
Industrial Facilities			
Initial Spares and Repair Parts			

(1) PM Office and contractor (Study Appendix H)
(2) PM Office (Study Appendix E)
(3) CCDR and contracts (Study Appendices J, O, P) Lower-level hardware costs available in CCDRs

Table 2.29: Production Phase Data

PRODUCTION	AAV (1)	LAV (2)	Stryker (3)	EFV (4)	Piranha III (5)	Cougar (6)	MTVR (7)	Bushmaster (6)	Caiman II (6)
Primary Vehicle		est	X		X	X	X	X	X
Hull/Frame	est	est							
Power Package/Drive Train	est								
Auxiliary Automotive	est	est							
Turret Assembly									
Fire Control									
Armament				X					
Body/Cab									
Automatic Loading									
Automatic/Remote Piloting									
Nuclear, Biological, Chemical									
Special Equipment									
Navigation									
Communications									
Primary Vehicle Application Software									
Primary Vehicle System Software									
Vetronics	est	est							
Integration, Assembly, Test and C/O	est								
System Engineering		est	X						
Program Management		est	X						
System Test and Evaluation		est	X						
Training		est	X						
Data		est	X						
Peculiar Support Equipment		est							
Common Support Equipment									
Operational/Site Activation									
Industrial Facilities									
Initial Spares and Repair Parts			X						

(1) PM Office and contractor (Study Appendix H)
(2) PM Office (Study Appendix E)
(3) CCDR and contracts (Study Appendices J, O, P) Lower-level hardware costs available in CCDRs
(4) CCDR and contracts (Study Appendix K) Lower-level hardware costs available in CCDRs
(5) Contract (Study Appendix L)
(6) Contracts (Study Appendix M)
(7) Contracts and PM Office (Study Appendix N)

2.15.2. DESCRIPTION OF CERS

Most of the 13 ground vehicle alternatives are based on existing vehicles and cost estimates are based on historical actuals, with a few variants requiring additional GFE integration or additional armor on the hull. No vehicle-level or hardware CERs are presented. Cost factors for contractor support are developed.

Table 2.30 shows the cost element structure followed in the AoA as well as the cost estimating methodology used for each element.

Table 2.30: Cost Estimating Methodology

Development Phase Cost Element Structure	Methodology
Alternative Development Phase Cost Estimate	sum
Contractor	sum
Hardware	sum
Non-Recurring	*f* (prototype AUC)
Recurring	*f* (prototype vehicle quantity, AUC)
Software	N/A
Contractor Support	*f* (Hardware $)
Government	sum
Government Furnished Equipment (GFE) Hardware	*f* (GFE quantity, GFE AUC)
Government Support	scaled analogy
Military Construction	USMC Thru-put

Production Phase Cost Element Structure	Methodology
Alternative Procurement Phase Cost Estimate	sum
Contractor	sum
Hardware	sum
Non-Recurring	*f* (Hardware $)
Recurring	*f* (quantity,AUC); adj for integrating GFE
Contractor Support	*f* (Hardware $)
Initial Spares	*f* (Hardware $)
Government	sum
Government Furnished Equipment (GFE) Hardware	*f* (GFE quantity,GFE AUC)
Government Support	Annual LOE analogy
War Reserve Ammunition	*f* (ammo quantity, ammo AUC)
Military Construction	USMC Thru-put

2.15.3. STRENGTHS AND WEAKNESSES

In general, the study provides a top-level comprehensive approach to estimating a variety of vehicle alternatives, including data.

A significant strength of the study is the breadth of vehicle level cost and pricing data across many systems. However, a significant weakness is the lack of detailed contractor cost data with visibility to lower levels beyond the all-up vehicle. The lower level subsystem data provided in the report is heavily dependent upon PM staff and contractor estimates. Additionally, the report relies upon estimates from the PM office for AAV and LAV rather than actual cost historicals.

No significant hardware cost estimating methodology is presented.

Only the Stryker production delivery orders provided data to develop contractor support cost factors; such data was unavailable from other analogous programs.

3: ASSESSMENT

There is a heavy bias toward Army systems. All but one of the studies reviewed were sponsored by the Army; the one other study was sponsored by the Marine Corps.

Cost estimating methodologies for the WTV commodity class ranged from fitted equations for CERs, generally at the vehicle level, to simple ratio relationships, typical for contractor support cost elements. Vehicle weight and horsepower are two of the prime vehicle-level parameters used in modeling. Because of differences in manufacturing processes, materials, system configuration, and missions, wheeled trucks and tracked combat vehicle are pooled and modeled separately.

The two primary Acquisition databases used by WTV cost analysts are the WTV ACDB module and the OSD DACIMS, which serves as the repository for Cost and Software Data Reports (CSDRs). ACDB draws upon DACIMS as well as contracts and EVM data, so there is overlap between the two primary databases. Navy VAMOSC and Army OSMIS provide USMC vehicle and Army vehicle operations and maintenance data, respectively. Cost data and technical data are supplemented by direct collection from the respective program office or from the organizations involved. Several of the studies are updates to prior editions, drawing from the previous established dataset and augmenting it with more recent years of data.

Data and analysis generally follow work breakdown structures (WBS) established in MIL-STD-881 and/or the complementary Army Cost Element Structure (CES) prescribed in the Army Cost Handbook. However, pooling and then filtering cost records to develop datasets and CERs that (1) are Wheeled or Tracked, (2) in the same phase, and (3) report to WBS Level 3, results in too small of samples to generate significant results – more data is needed.

The following table summarizes attributes addressed in the studies reviewed with respect to system type, study content, and life cycle phase.

Study Attributes	System Type			Study Content		Life Cycle Phase		
	Wheeled	Tracked	UGV	Data	CERs/Factors	Development	Procurement	O&S
WTV ACDB 2014	X	X		X		X	X	
BTL Factors 2014	X	X		X	X	X	X	
BFV $/lb 2014		X		X	X		X	
WTV GIH 2014	X	X		X		X	X	
VRB 2014	X	X		X		X	X	X
TDP 2014	X	X		X		X	X	
Mods 2014								
Cons&Reps 2013	X			X	X			X
Rates Uncertainty 2013	X	X		X	X	X	X	
LC Step-Down 2012		X		X	X	X	X	
BlueBook 2012	X	X		X	X	X	X	
UGV 2011			X	X	X		X	
Competition 2009	X	X			X		X	
MRAP 2007	X			X	X		X	
MPC AoA 2007	X			X	X	X	X	X

Across the 15 studies reviewed, there is a balance in data collection and analysis between the Wheeled systems and Tracked systems, with a single Unmanned Ground Vehicle system addressed. The number of active major Wheeled programs is approximately equal to the number of major Tracked combat vehicle programs, which may explain the relative balance in cost reporting, cost data, and cost research. In general, the Wheeled vehicle systems have lower average unit cost relative to Tracked combat vehicle systems, but are bought at much greater quantities.

Thirteen of the studies include cost and/or technical and/or programmatic information. Despite the relatively large number from this sample of 15 studies, there are only a handful of studies that address WBS Level 3 or lower. There is simply not much data or many programs that have hardware cost data at the subsystem level, making CER development difficult. When faced with this, many analysts estimate ground vehicle costs via analogy.

Thirteen of the studies address procurement costs, and nine of those also address development costs. Analysts need to be cautious when collecting and using development phase cost data from the WTV commodity. Many programs are derivative or upgrades of processor system, and not brand new, successful development. Looking at Tracked combat vehicles, for example, the last development program that was completed successfully and carried into production was from the late 1970s for both the M1 Abrams Main Battle Tank (MBT) and the M2/M3 Bradley Fighting Vehicle (BFV). (The XM1203 Non-Line-of-Sight Cannon (NLOS Cannon) was a mobile 155 mm cannon as part of the (cancelled) US Army's Future Combat Systems (FCS) program. A total of eight prototypes were delivered to the U.S. Army. Similarly, the Marine Corps developed the Expeditionary Fighting Vehicle, but it too was cancelled before it made it to production.) Little work has been done in our sample of fifteen WTV studies in O&S Phase cost estimating methodology, with only three studies including either O&S Phase data or analysis.

Generally, the databases and studies follow the MIL-STD-881 Appendix G, Surface Vehicle Systems. The following two tables indicate the WBS element(s) that are addressed in each of the fifteen studies reviewed.

Development	WTV ACDB 2014	BTL Factors 2014	BFV $/lb 2014	WTV GIH 2014	VRB 2014	TDP 2014	Mods 2014	Cons&Reps 2013	Rates Uncertainty 2013	LC Step-Down 2012	BlueBook 2012	UGV 2011	Competition 2009	MRAP 2007	MPC AoA 2007
Surface Vehicle System	X	X			X				X						
Primary Vehicle	X	X							X		X				X
Hull/Frame	X	X								X					
Suspension/Steering	X	X								X					
Power Package/Drive Train	X	X								X					
Auxiliary Automotive	X	X								X					
Turret Assembly	X	X								X					
Fire Control	X	X								X					
Armament	X	X													
Body/Cab	X	X													
Automatic Loading	X	X													
Automatic/Remote Piloting	X	X													
Nuclear, Biological, Chemical	X	X													
Special Equipment	X	X								X					
Navigation	X	X													
Communications	X	X													
Primary Vehicle Application Software	X	X													
Primary Vehicle System Software	X	X													
Vetronics	X	X													
Integration, Assembly, Test and Checkout	X	X								X					
Systems Engineering/Program Management	X	X		X							X				X
System Test and Evaluation	X	X		X							X				X
Training	X	X									X				X
Data	X	X				X					X				X
Peculiar Support Equipment	X	X									X				
Common Support Equipment	X	X									X				
Operational/Site Activation	X	X													
Industrial Facilities	X	X													
Initial Spares and Repair Parts	X	X													

Production	WTV ACDB 2014	BTL Factors 2014	BFV $/lb 2014	WTV GIH 2014	VRB 2014	TDP 2014	Mods 2014	Cons&Reps 2013	Rates Uncertainty 2013	LC Step-Down 2012	BlueBook 2012	UGV 2011	Competition 2009	MRAP 2007	MPC AoA 2007
Surface Vehicle System	X	X	X		X				X						
Primary Vehicle	X	X	X						X	X	X	X		X	X
Hull/Frame	X	X	X								X				
Suspension/Steering	X	X	X								X				
Power Package/Drive Train	X	X	X								X				
Auxiliary Automotive	X	X	X								X				
Turret Assembly	X	X	X								X				
Fire Control	X	X	X								X				
Armament	X	X	X												X
Body/Cab	X	X													
Automatic Loading	X	X													
Automatic/Remote Piloting	X	X													
Nuclear, Biological, Chemical	X	X	X												
Special Equipment	X	X													
Navigation	X	X													
Communications	X	X	X												
Primary Vehicle Application Software	X	X													
Primary Vehicle System Software	X	X													
Vetronics	X	X													
Integration, Assembly, Test and Checkout	X	X	X								X				
Systems Engineering/Program Management	X	X		X							X				X
System Test and Evaluation	X	X		X							X				X
Training	X	X													X
Data	X	X				X									X
Peculiar Support Equipment	X	X									X				
Common Support Equipment	X	X									X				
Operational/Site Activation	X	X													
Industrial Facilities	X	X													
Initial Spares and Repair Parts	X	X									X				X

The strengths of these studies are the variety of subject matter covered and breadth of data and analysis, and the recency of the bodies of work. The studies provide good launching points for further data collection and analysis. The weakness of these studies is the unfortunate lack of estimating relationships at lower levels of detail. Only a few of the studies address the O&S phase of a WTV system.

4: NEEDS AND FUTURE RESEARCH

4.1. GRANULARITY

Continuing to collect data, and at WBS Level 3 and lower, is needed. As with all weapon system commodities, cost estimating methodologies rely on cost, technical, and programmatic data. This literature review of fifteen WTV studies reveals the same need, and reveals a gap in data for major subcomponents and subassemblies, that is WBS Level 3 and lower. In order to support Analysis of Alternatives, Independent Cost Estimates, Design Trade studies, and Cost Benefit Analysis, these lower level WBS elements require a base of historical raw data and cost analysis.

Government executives, managers, and senior cost analysts can work together to ensure that major weapon programs develop cost reporting plans for each major contract, and that the level of detail be sufficient to support future cost estimates. Future weapon cost databases updates should include more systematic collection of cost and with greater granularity in WTV subsystem data; this greater detail will support development of WBS Level 3 CERs at a minimum, and allow analysts to more easily perform design trades.

4.2. O&S COSTS

O&S costs make up a significant portion (~50%) of a WTV system's life cycle cost, and yet, relative to development and production phases, few studies present cost estimating methodologies for O&S cost elements. After manpower costs, depot costs are among the top two or three cost drivers in O&S for WTV systems. Future depot cost data collection and analysis is required to generate credible LCC estimates, and to enable informed decision-making, for example, as services weigh the costs of extending a systems life through overhaul or Service Life Extension Programs (SLEPs) or start a new replacement program.

4.3. WTV SYSTEM EVOLUTION

Understanding WTV system histories and configuration evolution is necessary when using historical cost data as a basis for estimating future systems. Most WTV programs start out as (or grow into) a Family of Vehicles (FOV), with many variants performing different missions, but

all relying upon a similar base platform. In addition, many WTV systems evolve over time with upgrades, modification programs, ECP programs and SLEPs. Distinguishing among variants is often only observed at Level 3 of the WBS or lower levels. For example, one variant of a tank may have an updated fire control system or updated components within a fire control system. Care must be taken when collecting cost data and normalizing for prior quantity, production concurrency, design commonality; this requires a retrospective history of WTV system evolution.

4.4. ACAT II AND ACAT III PROGAMS

Army and Marine Corps program offices and the OSD DCARC office have made a concerted effort over the last decade to enforce CSDR requirements on all active ACAT I programs, including WTV programs, and ensure the CSDR requirement is placed on contract in accordance with DoDM 5000.04-M-1 in accordance with the authority in DoD Directive 5000.04 and DoD Instruction 5000.02. These CSDRs form a base for WTV databases and cost estimating methodologies. However, many Army and Marine Corps WTV programs fall below the ACAT I threshold, and are not required to deliver MIL-STD-881 compliant CSDR reporting. CSDRs are discretionary for ACAT II and III programs. Capturing ACAT II and ACAT III programs in a central repository would increase the availability and accessibility of valuable data on small programs.

5: FURTHER READING

"LIFE CYCLE ENVIRONMENTAL COST ANALYSIS FOR THE CRUSADER PROGRAM," Raj Ramaswamy, 1999, SCEA/ISPA

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